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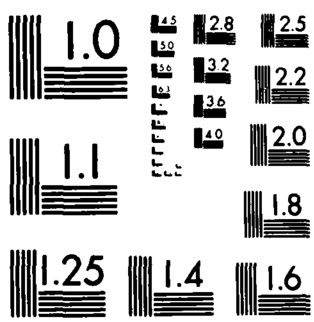

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HFE TECHNOLOGY

FOR

NAVY WEAPON SYSTEM ACQUISITION

Contract N00024-76-C-6129

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— FINAL REPORT —

HUMAN FACTORS ENGINEERING FOR NAVY WEAPON SYSTEM ACQUISITION

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NAVAL SEA SYSTEMS COMMAND
Washington, D.C. 20362

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July 1979

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ACKNOWLEDGEMENTS

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ABSTRACT

The recognition of a need for a detailed assessment of the role and timing of Human Factors Engineering (HFE), in the process of acquiring major naval weapon systems, was precipitated by the publication of the report Human Factors Engineering for Navy Ship Systems Acquisitions, ESSEX Corporation, August 1976. Three tasks were performed in the preparation of the present report: (1) The Navy Weapon System Acquisition process was defined, with supporting documentation. Major acquisition phases, milestones, events and activities were identified and formatted into a timeline. (2) A comprehensive review of the scientific literature was conducted in order to identify viable HFE methods, techniques, principles and data. These technologies were then described, along with methods of application for each. (3) An extensive assessment was made of each technology, in terms of meeting HFE requirements, as well as applicability and appropriateness within the acquisition cycle.

The report is presented in four sections: Section 1, the Introduction, provides general background information and defines the approach taken; Section 2 defines the Navy Major Weapon System Acquisition process and identifies HFE requirements within that process. Forty-seven major acquisition events, activities and milestones and 45 general HFE requirements are discussed; Section 3 provides descriptions of over 70 HFE methods and techniques, as well as HFE principles and data sources. In addition, each method and/or technique is assessed according to its applicability to HFE requirements within the acquisition cycle; (4) the final section identifies HFE technology shortfalls in terms of addressing the HFE requirements. It also identifies several emerging technologies that are suitable to fill the identified technology gaps.

The effort was conducted under contract number N00024-76-C-6129, "Human Factors Engineering Technology for Ships," for the Naval Air Development Center and the Naval Sea Systems Command (Code 03416).

1.0 INTRODUCTION

1.1 Background

In October 1976, the ESSEX Corporation published a report for the Naval Sea Systems Command (Sea 034) entitled "HFE Technology for Ship Acquisition". The purpose of the report was to integrate Human Factors Engineering (HFE) Technology with the Naval ship acquisition process. This entailed addressing six separate considerations:

1. The specific design activities, directives and milestones of the acquisition process.
2. HFE requirements as they relate to each activity and event of the process.
3. The interrelationships among different HFE requirements.
4. The available HFE technologies which are applicable to HFE requirements.
5. The interrelationships among HFE technologies and the activities in the Naval ship acquisition process.
6. The technology shorfalls or gaps in the technology base.

The report itself was published as two volumes. Volume I consists of: (1) an overview of the phase activities in the ship acquisition process; (2) identification of HFE requirements in each phase; (3) methods of satisfying HFE requirements (at the time of the report); (4) identification of HFE problem areas in the ship acquisition process; and (5) for the areas of manning and training, design for operability, design for habitability, design for maintainability and test and evaluation. The report describes:

- Requirements and issues
- The assessment of applicable and available HFE technology
- The identification of technology gaps and trends
- Recommendations.

Volume II of the report contains detailed information relevant to item 5, above.

1.2 HFE for Major Naval Weapon Systems Acquisition

An outgrowth of the 1976 HFE integration report was the recognition that a requirement existed for a similar effort, to be directed towards all naval major weapon system acquisitions. In response to this requirement a project was initiated that has as its objective to survey and assess: (1) major milestones and events in the Navy major weapon system acquisition process; (2) human factors engineering requirements and technologies

as they apply to the acquisition process; and (3) HFE technology shortfalls related to the acquisition process.

1.3 Approach

The approach taken to meet the study objectives are described below in terms of four tasks.

Task 1 - Define the Navy Major Weapon System Acquisition Process.

- Identify the phases of the major weapon system acquisition process
- Identify major milestones, events and activities in each major phase
- Identify input, output and decision requirements for each major milestone, event and activity
- Identify products and information outputs for each major milestone, event and activity
- Format acquisition cycle into a timeline with accompanying text.

Task 2 - Survey Human Factors Engineering Technology.

- Survey available and emerging HFE methods, techniques, principles and data
- Classify technologies
    - descriptive
    - analytic
    - design-oriented
    - evaluation/assessment-oriented
    - integrative
- Describe technology in terms of:
    - objective
    - source
    - application
    - state of development
    - problems identified
- Describe each technology method of application

Task 3 - Assess and Integrate HFE Technology With the Acquisition Process.

- Identify HFE requirements at each step of the acquisition cycle
- Develop and apply criteria for technology assessment according to:
    - usability
    - impact on system design
    - cost
    - alternative technologies
    - potential for computerization
    - standardization
- Identify HFE inputs to products of the acquisition cycle
- Identify acquisition cycle information inputs to HFE activities

- Identify HFE windows (time periods) wherein required events must be completed with indications of consequences of failure
- Format acquisition cycle and HFE design process into a timeline
- Identify HFE technology shortfalls

Task 4 - Prepare Report. This task required the consolidation and codification of information gathered in the previous tasks. Data in the report is presented in four sections, as follows:

1. Introduction
2. Navy major weapon system acquisition process integration with Human Factors Requirements
   - Acquisition process (with major phases, milestones, activities)
   - HFE process and requirements
   - HFE inputs to the acquisition cycle
   - Acquisition cycle major event and activities inputs to H' process
3. Survey of the applicability of HFE methods, techniques, principles a data to specific HFE requirements within the acquisition process.
4. Statements of identified technology shortfalls, identification of emerging HFE techniques and methods suitable to fill technology shortfalls.

2.0 NAVY WEAPON SYSTEMS ACQUISITION PROCESS

2.1 Formal Acquisition Policy

In April, 1976, the Office of Management and Budget (OMB) released Circular Number A-109 which establishes policies for acquisition of major systems. This document details the responsibilities and issues to be addressed in acquiring systems. OMB Circular Number A-109 is provided in Appendix B.

Three basic documents direct the Navy (and all other services) in implementing the requirements of A-109. These are Department of Defense (DoD) Directives 5000.1, 5000.2 and 5000.3.

DoD Directive 5000.1, "Major Systems Acquisitions" (January 1977), provides basic system acquisition policy for systems costing over $75 million research, development, test and evaluation (RDT&E) or over 300 million procurement dollars. Acquisition policy as set forth in the Directive is summarized briefly as follows:

- Acquisition is a sequence of phases initiated by approval of a mission need.
- DoD components (Army, Navy, Air Force) are to analyze and identify mission needs, and to develop systems which fulfill those needs.
- The Secretary of Defense (SECDEF) renders decisions regarding program commitments (to initiate programs, direct program funding). Four SECDEF decision points are identified:
    - Milestone 0 - Program initiation
    - Milestone I - Demonstration and validation
    - Milestone II - Full-scale engineering development
    - Milestone III - Production and deployment

  The Milestone 0 decision requires that a mission need is demonstrated in a document called the Mission Element Need Statement (MENS). The Milestone I decision (to procede to the next phase) is based on recommendations documented in the Decision Coordinating Paper (DCP). The Milestone II and III revisions are based on updated revisions of the DCP.
- Mission needs are to be satisfied, where feasible, with existing hardware and software.
- Test and evaluation is to be commenced as early as possible.
- Alternate maintenance concepts are part of logistic support planning.
- Human engineer factors are to be included as constraints in system design. "The integration of the human element and system shall start with the initial concept studies and refined as the system program progresses to form the basis for personnel selection and training, training devices, simulators and planning related to human factors."

DoD Directive 5000.2, "Major System Acquisition Process" (January 1977), establishes the process by which major systems are acquired. It establishes that the SECDEF

will exercise direction and control of acquisition programs through four milestone decisions concerning further program conduct. It further establishes advisory councils to review DCPs and make recommendations concerning program direction and continuation. The Defense System Acquisition Review Council (DSARC) (Tri Service) and Department of the Navy System Acquisition Review Council (DNSARC) are so chartered as the organizations for Navy acquisitions.

DoD Directive 5000.2 also describes required documentation to support DSARC and SECDEF acquisition program reviews, recommendations and decisions; these include the Mission Element Need Statement (MENS) and the DCP. The MENS is used by the SECDEF at the initial decision point, Milestone 0 (program initiation), and ultimately becomes part of the DCP and DSARC process.

The directive also schedules program reviews and SECDEF decision making. Four program reviews (milestones) are called for by DoD Directive 5000.2.

- Milestone 0 - Program initiation
- Milestone I - Demonstration and validation
- Milestone II - Full-scale engineering development
- Milestone III - Production and deployment

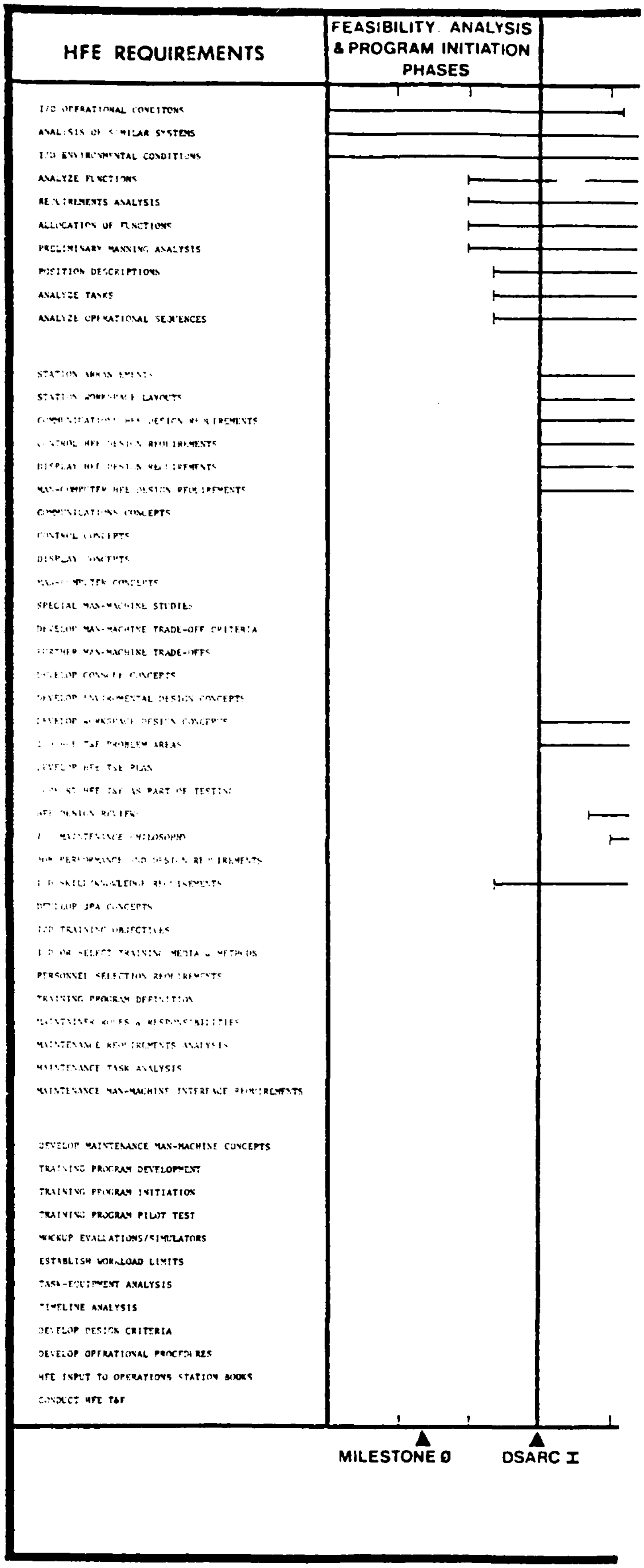
At Milestone 0, the SECDEF makes the decision concerning program initiation by reviewing the MENS; at Milestones I, II and III, the SECDEF makes program decisions utilizing the DCP and DSARC recommendations. The activities conducted prior to each of the milestones are depicted in Figure 1.

DoD Directive 5000.3, "Test and Evaluation" (1977), determines that all systems will be subject to test and evaluation (T&E) and will be part of the DSARC and SECDEF Milestone decisions.

Four general principles are set forth by the directive:

1. T&E shall be commenced as early as possible in the acquisition cycle, and shall be conducted throughout.
2. Acquisition schedules will be based on accomplishing T&E Milestones.
3. T&E of existing or modified equipment may be performed prior to the initiation of a new system development, in order to help define military need and estimate military utility of the new system.
4. T&E activities shall consider environmental issues and provide assessments for review as early as possible in the test planning cycle.

The directive also requires that integrated T&E plans be established and kept current with all system T&E efforts and schedules. This plan is to be established as early


HFE REQUIREMENTS
FEASIBILITY ANALYSIS & PROGRAM INITIATION PHASES
I/D OPERATIONAL CONDITIONS
ANALYSIS OF SIMILAR SYSTEMS
I/D ENVIRONMENTAL CONDITIONS
ANALYZE FUNCTIONS
REQUIREMENTS ANALYSIS
ALLOCATION OF FUNCTIONS
PRELIMINARY MANNING ANALYSIS
POSITION DESCRIPTIONS
ANALYZE TASKS
ANALYZE OPERATIONAL SEQUENCES
STATION ARRANGEMENTS
STATION WORKSPACE LAYOUTS
COMMUNICATIONS HFE DESIGN REQUIREMENTS
CONTROL HFE DESIGN REQUIREMENTS
DISPLAY HFE DESIGN REQUIREMENTS
MAN-COMPUTER HFE DESIGN REQUIREMENTS
COMMUNICATIONS CONCEPTS
CONTROL CONCEPTS
DISPLAY CONCEPTS
MAN-COMPUTER CONCEPTS
SPECIAL MAN-MACHINE STUDIES
DEVELOP MAN-MACHINE TRADE-OFF CRITERIA
FURTHER MAN-MACHINE TRADE-OFFS
DEVELOP CONSOLE CONCEPTS
DEVELOP ENVIRONMENTAL DESIGN CONCEPTS
DEVELOP WORKSPACE DESIGN CONCEPTS
T&E PROBLEM AREAS
DEVELOP HFE T&E PLAN
HFE T&E AS PART OF TESTING
HFE DESIGN REVIEWS
MAINTENANCE PHILOSOPHY
JOB PERFORMANCE AND DESIGN REQUIREMENTS
I/D SKILL/KNOWLEDGE REQUIREMENTS
DEVELOP JPA CONCEPTS
I/D TRAINING OBJECTIVES
I/D OR SELECT TRAINING MEDIA & METHODS
PERSONNEL SELECTION REQUIREMENTS
TRAINING PROGRAM DEFINITION
MAINTAINER ROLES & RESPONSIBILITIES
MAINTENANCE REQUIREMENTS ANALYSIS
MAINTENANCE TASK ANALYSIS
MAINTENANCE MAN-MACHINE INTERFACE REQUIREMENTS
DEVELOP MAINTENANCE MAN-MACHINE CONCEPTS
TRAINING PROGRAM DEVELOPMENT
TRAINING PROGRAM INITIATION
TRAINING PROGRAM PILOT TEST
MOCKUP EVALUATIONS/SIMULATORS
ESTABLISH WORKLOAD LIMITS
TASK-EQUIPMENT ANALYSIS
TIMELINE ANALYSIS
DEVELOP DESIGN CRITERIA
DEVELOP OPERATIONAL PROCEDURES
HFE INPUT TO OPERATIONS STATION BOOKS
CONDUCT HFE T&E
MILESTONE Ø
DSARC I

as possible in the acquisition cycle, and must be completed prior to Milestone II. Further requirements for T&E, as part of the DSARC process, are stated. Briefly, these are:

- The DCP at Milestone I will identify critical questions and areas of risk to be resolved by T&E
- The DCP at Milestone II will provide results of T&E efforts to that date and update critical questions and areas of risk
- DSARC will review T&E results prior to making recommendations to the SECDEF at Milestone III.

The above documents provide direction during the acquisition process. Another document, MIL-H-46855, "Human Engineering Requirements for Military Systems, Equipment and Facilities, is directed specifically at the role of HE in the acquisition process.

This specification states that human factors program requirements are to include:

- Defining and allocating system functions. Human Factors Engineering principles and criteria are to be applied to allocate system functions to
  - automatic operations/maintenance
  - manual operation/maintenance or
  - a combination of manual/automatic operation/maintenance
- Information flow and processing analysis
- Estimates of potential operator/maintainer processing capabilities. Roles to be identified for humans such as
  - operator
  - maintainer
  - programmer
  - decision maker
  - communicator
  - monitor

  are required. Estimates concerning load, accuracy, rate, etc., are also to be identified
- Equipment identification. HFE principles and criteria are to be incorporated into the identification or selection of equipment which are to be operated/controlled/maintained by man.
- Task analysis. To be conducted and applied to design decisions, analysis of manning levels, equipment procedures, etc.
- Analysis of critical tasks. Task analysis (above) extended to analysis of critical tasks to identify, for example:
  - information required by man
  - information available to man
  - information evaluation process
  - decision reached
  - action taken
  - body movements
  - tool required
  - job performance aids (JPA) required
- Loading analysis. Crew/individual workload analysis is to be applied and compared to performance criteria.

- Preliminary system and subsystem design. HFE principles and data are to be applied to system/subsystem design. MIL-STD-1472 is to be complied with.
- Detailed design. As above.
- Studies, experiments, laboratory tests. Research is to be conducted to resolve man/machine trade-off problem areas and other HFE and life support problems.
- Mock-ups and models. Mock-ups (3-D) to be constructed as an HFE design evaluation tool.
- Dynamic simulation (as required for HFE design).
- Design drawings.
- Workspace environment. This would include
  - atmospheric conditions
  - weather and climate
  - bodily acceleration
  - noise
  - safety (handholds, etc.)
- Test and evaluation. Planning, implementation and failure analysis.

Figure 2 shows functional relationships of MIL-H-46855 Human Factors Requirements (adapted from Geer, 1976).

2.2 Requirements Throughout the Acquisition Cycle

HFE requirements and the Navy major weapon system acquisition cycle are presented in Figure 1. Requirements, inputs, outputs and uses for each HFE step are shown in Table 1. The schedule of applying HFE requirements is presented in Figure 3. The following text describes, for each phase, HFE requirements and major acquisition steps.

There are five acquisition phases, each leading to a program milestone. These are: (1) feasibility/analysis; (2) program initiation; (3) demonstration and validation; (4) full-scale engineering development; and (5) production and deployment.

TABLE 1

REQUIREMENTS, INPUTS, OUTPUTS AND USES FOR EACH STEP OF THE HUMAN FACTORS ENGINEERING PROCESS

HFE Requirement	Inputs	Outputs	Use
1. Operational Conditions Identification	• Mission data • Similar system data • Tactical data • Mission Element Needs Statement (MENS)	• Conditions affecting system operation • HFE "Design to" considerations	• Begin early development of HFE Design Criteria • Input to subsequent analyses, e.g., - environmental - similar systems - requirements, etc.
2. Similar Systems Analysis	• Human performance data for similar systems, specifically relating to HFE areas of: - operability - maintainability - manning and training • Science & Technology Objectives (STO) • System mission requirements	• Historical HFE design problem areas • Design baseline • Potential design constraints • Lessons learned	• Further identification of HFE Design Criteria • Input to: - requirements analysis - task analysis - functional allocations - position descriptions - identification of HFE T&E problem areas
3. Environmental Conditions Identification	• Mission data • Tactical data • Areas of potential system deployment	• Conditions affecting system operations and maintenance • HFE "design to" considerations	• Development of HFE Design Criteria • Identification of system support criteria
4. Requirements Analysis	• Mission data • Tactical requirements • System functions • MENS • STOs	• Statements of system capabilities • System operational requirements • Readiness requirements	• Input to: - functional allocations - manning analysis • Development of HFE Design Criteria in forms of mission/task criticalities

TABLE 1
(Continued)

HFE Requirement	Inputs	Outputs	Use
5. Functional Analysis	• Preliminary system concepts • Similar systems • Selected subsystems • Proposed subsystems • MENS • STOs	• System functions • Synchronization and dependency of functions • Functional hierarchy • Critical functions	• Man-machine trade-offs • Input to: - functional allocations - task analysis - operational sequence analysis - manning analysis - training system development
6. Functional Allocation	• Similar system data • Level of system automation • Relative capabilities • System functions • Requirements and criticality data • Manning requirements • Identifed systems	• Functions assigned to men or machines • Functions further assigned to individual operators • Role of man in the system is specified in general terms	• HFE design initiated • Input to: - position description - task analysis - Operational sequence analysis - training system development
7. Preliminary Manning Analysis	• Functional allocations • Analysis of allocations	• Potential areas of operator over/under load	• Iteration of functional allocations • Training system development • Input to DCP
8. Position Description	• Functional allocations	• Operator duties - each position	• Documentation of functional allocations • Input to: - task analysis - operational sequence analysis

TABLE I
(Continued)

HFE Requirement	Inputs	Outputs	Use
9. Task Analysis	• Functional allocations • Requirements analysis • Similar systems • Operational and environmental conditions • System functions and sequences	• Task descriptions • Task requirements • Task sequences • Task criticalities	• Design criteria development • Analysis of functional allocations • Input to: - operational sequence analysis - station design - identification of HFE T&E problem areas - training system development
10. Operational Sequence Analysis	• Functional allocations • Task analysis • Task sequences • Task dependencies • Task interactions	• Operational sequences • Operator interactions • Decision sequences	• Basic input to station design • Training system development • Evaluation of functional allocations
11. Stations Arrangements	• Operational sequence analysis • Task analysis • Functional allocations • Identified systems	• Station links identified • Communications requirements	• Design of communication system • Input to workspace layouts
12. Station Workspace Layouts	• Station links • Number of station links by mode and criticality	• Workstation layout minimizing communication support requirements	• System HFE design
13. Communications HFE Design Requirements	• Station links • Link criticalities • Information requirements	• Required messages • Modes of communication • Standard messages	• Communication system design - transmission mediums - message standardization

TABLE I
(Continued)

HFE Requirement	Inputs	Outputs	Use
14. Control HFE Design Requirements	• Functional allocations • Task analysis • Operational sequence analysis • Communications requirements • Requirements analysis • Operational and environmental conditions	• Control requirements: - importance - criticality - frequency of use - precision - feedback - type of actions	• Control type selection • Control: - size - shape - color
15. Display HFE Design Requirements	• Control requirements • Communications requirements • Operational sequences • Requirements analysis • Environmental and operational conditions • Task analysis	• Display requirements - information displayed - type - criticality - update rates - associated controls - duration - accuracy - readability	• Display type selection • Display - size - color - shape
16. Man-Computer HFE Design Requirements	• Requirements analysis • Functional allocations • Task analysis • Operational sequences	• Interface requirements: - input/output - monitoring - operation - override - information requirements - control/display requirements - feedback	• Programming considerations • Training requirements

TABLE I
(Continued)

HFE Requirement	Inputs	Outputs	Use
17. Communications Concepts	• Links • Communication requirements • Analysis of similar systems • Station layouts • Task analysis	• Design constraints and requirements • Alternate feasible concepts	• Trade-offs • Concept development with constraints
18. Control Concepts	• Control requirements • Analysis of similar systems • Control type options • Task analysis	• Control design constraints and requirements • Alternate feasible concepts	• Trade-offs • Control system design
19. Display Concepts	• Control requirements and concepts • Similar systems • Task analysis • Display type options • Control feedback requirements	• Display constaints and requirements • Alternate feasible concepts	• Trade-offs • Console design concepts
20. Man-Computer Concepts	• Man-computer requirements • Task analysis • Similar systems	• Computer constraints and requirements • Alternate feasible concepts	• Trade-offs • Interface concept development

TABLE I
(Continued)

HFE Requirement	Inputs	Outputs	Use
21. Man-Machine Trade-off Studies	• Requirements for additional human performance data for specific functional areas • Study plan • Apparatus setup	• Workload data • Procedural data • Skill requirements • Design approach effectiveness • Performance data	• Development of man-machine trade-off criteria • Inputs to trade-offs of alternate concepts
22. Develop Man-Machine Trade-off Criteria	• Trade-off studies • Task requirements • Similar systems • Control concepts • Display concepts • Communications concepts • Man-computer interface • System requirements	• Further allocations of functions to man-machine • Functional reallocations	• Equipment design issues - controls - display - communications - layouts - procedures - job performance aid development - training system development • Identify maintainability issues • Identify HFE T&E issues
23. Develop Console Concepts	• Trade-off results • Operational sequences • Task analysis • Design criteria • Similar systems • Control/display/communications concepts	• Panel/workspace: - layouts - shapes - locations - sizes - colors	• Workspace/panel design concepts evaluation • Procedures design • Environmental design • Equipment prototyping
24. Environmental Design Concepts	• Environmental conditions • Environmental constraints • Human limitations	• "Design to" criteria • Compensated factors	• Modes of environmental compensation

TABLE I
(Continued)

HFE Requirement	Inputs	Outputs	Use
25. Workspace Concepts	• Console concepts • Equipment requirements • Environmental design concepts • Links • Constraints	• Arrangement criteria • Criteria weights	• Development of workspace concepts; - layouts - illumination levels - visual envelopes - emergency escape routes - volume, etc.
26. Identify HFE T&E Problem Areas	• Similar systems data • Task analysis • Operational sequences • Environmental and operational conditions	• Potential safety problems • Potential performance problems • Potential information transfer and dissemination areas • Potential manning and training problem areas	• Input to: - HFE T&E Plan - T&E issues - T&E materials • Input to TEMP
27. Develop HFE T&E Plan	• HFE T&E problem areas • "Design to" issues • Design requirements • HFE data bases: - anthropometry - human performance - design principles, etc.	• HFE T&E Test Plan: - issues - criteria - scheduling, etc.	• HFE T&E as part of TEMP • Support T&E as part of design
28. Conduct Design Reviews	• HFE T&E Plan • HFE T&E data	• Redesign requirements: - functional allocations - control/display/communications concepts - workspace layouts - environmental design	• HFE design requirements

TABLE I
(Continued)

HFE Requirement	Inputs	Outputs	Use
29. Identify Maintenance Philosophy	• Integrated Logistics Support Master Plan	• Maintenance philosophy - level of repair - consumables - planned maintenance - corrective maintenance - repair, replace, etc.	• Maintainability design imput • Training system development • Job performance aid development
30. Job Performance Aids (JPA) Design Requirements	• Task analysis • Operational sequences • Information requirements • Task characteristics	• JPA requirements • JPA trade-off criteria	• Training vs. JPA decision for task sequences • Training system/JPA development • Training system development
31. Develop JPA Concepts	• JPA requirements • Skill/knowledge requirements • Constraints	• JPA criteria • JPA concept development • Trade-off criteria	• JPA trade-offs • JPA development • Training system development
32. Identify Training Objectives	• Task analysis • Skill/knowledge requirements • Training/JPA decision • Performance standards and requirements	• Training objectives: - skill levels - knowledge levels - performance standards - performance conditions for selected tasks • Level of training detail	• Training system development

TABLE I
(Continued)

HFE Requirement	Inputs	Outputs	Use
33. Identify/Select Training Media and Methods	• Skill/knowledge requirements • Training objectives	• Course requirements - methods: - self-paced instruction - tests and test requirements - instructor requirements • Course requirements - media: - training objective priorities - simulation - visual presentation of information - textual presentation - formats, etc.	• Training system media and methodology selection • Course requirements become course objectives
34. Personnel Selection Requirements	• Skill/knowledge requirements • Training objectives • Manpower availability	• Personnel selection criteria	• Personnel selection
35. Training Program Definition	• Training media and methods • Training objectives	• Program definition - course objectives - information presentation media - training success requirements - test requirements, etc.	• Training system development
36. Maintainer Roles and Responsibilities	• Maintenance philosophy	• Identified maintenance requirements: - planned maintenance - corrective maintenance	• Maintainability design

TABLE I
(Continued)

HFE Requirement	Inputs	Outputs	Use
37. Maintenance Requirements Analysis	• System/subsystem engineering design • Maintenance philosophy - level of repair - planned maintenance - corrective maintenance	• Accessibility requirements • Support requirements - tools - test points - JPAs, etc. • General design requirements	• Input to: - maintainability task analysis - identification of maintenance interface design requirements
38. Maintenance Task Requirements Analysis	• Maintenance philosophy • Maintenance requirements analyses	• Identified maintenance activities • Maintenance functions and tasks developed • Task sequences • Branching tasks identified • Task requirements identified	• Input to maintenance interface requirements and maintainability design • Input to maintenance training system development
39. Maintenance Man-Machine Interface Requirements and Concepts	• Maintenance task analysis • Maintenance requirements analysis	• Maintenance man-machine interfaces • Interface requirements: - information displays - controls - decision requirements • Workspace layouts and arrangements • Environmental and operational conditions • Personnel and training requirements • Maintainability issues identified	• Maintainability design concept generation: - layouts - JPAs - environmental design - training, etc.

TABLE I
(Continued)

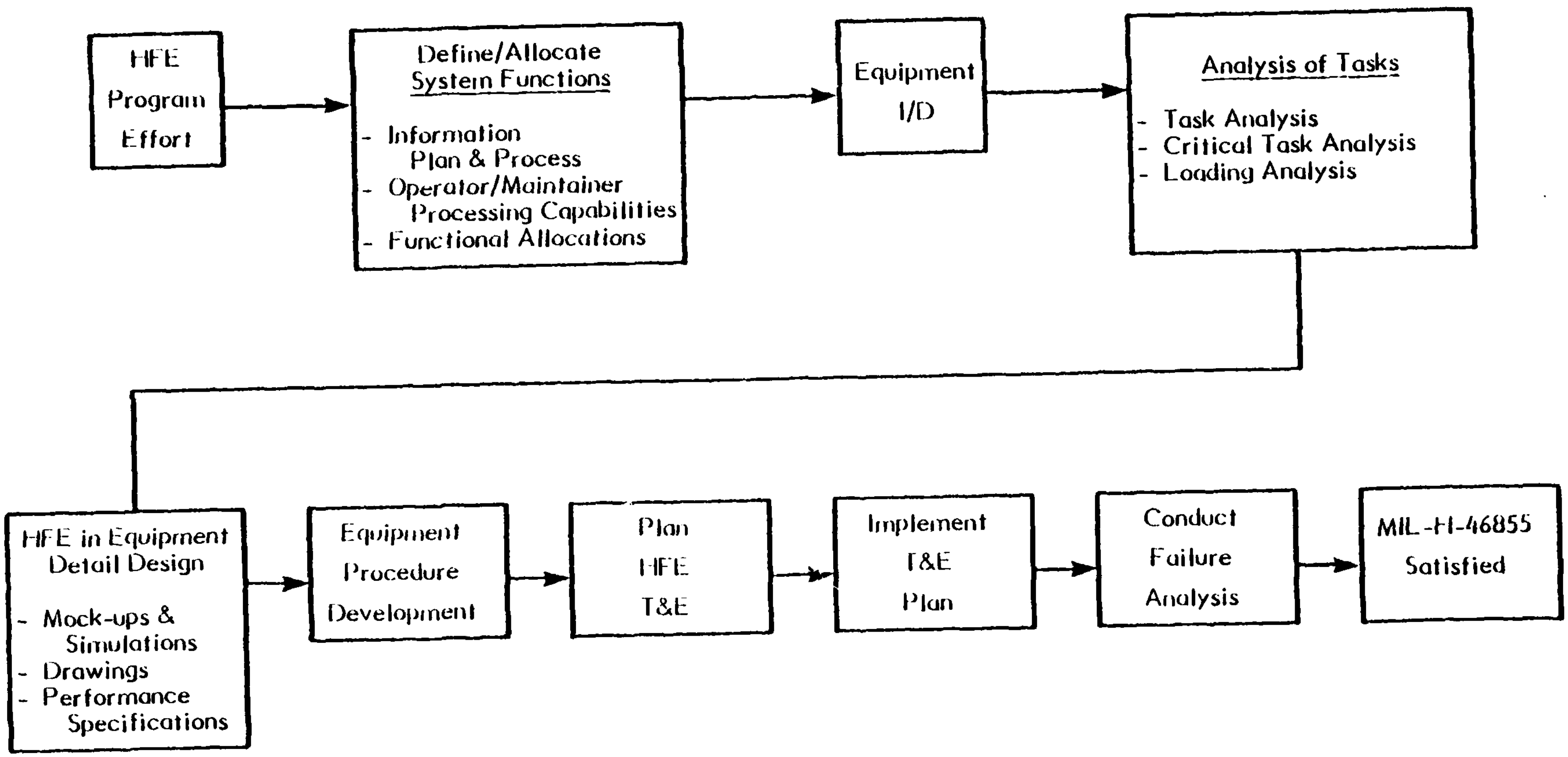
HFE Requirement	Inputs	Outputs	Use
40. Training Program Development, Initiation, and Pilot Test	• Training objectives • JPA concepts • Training media and methods selection • Training requirements	• Training system: - developed - applied - tested	• Training system demonstration
41. Mockup Evaluations/Simulations	• Test plans • Operational sequences • HFE design criteria • Performance criteria • Workspace concepts • Console concepts • Training system requirements • Test and evaluation materials	• Design: - verification - documentation - experimentation • Workloads • Trade-off criteria • Problem identification	• Design iteration • Design criteria development • Design review • Procedures review
42. Establish Workload Limits	• T&E data • Mockup data • Operational sequences • Mission analysis • System/mission requirements	• Absolute workload limits for task sequences within mission segments	• Design criteria

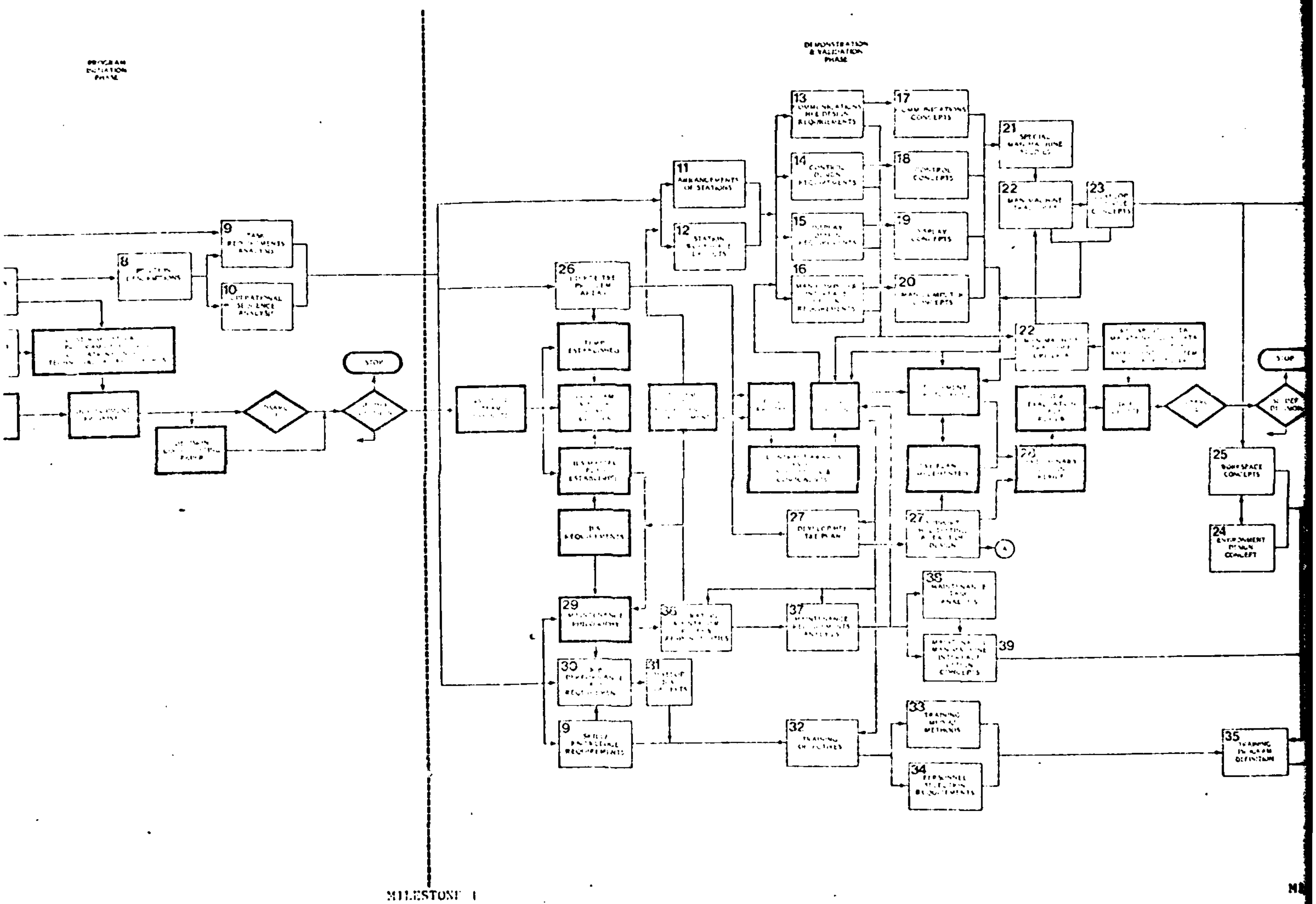
TABLE 1
(Continued)

HFE Requirement	Inputs	Outputs	Use
43. Task-Equipment Analyses	• Operational procedures • Workspace concepts • Console layouts • Control/display/communications requirements	• Sequential task descriptions: - control activities - display references/ response times - equipment locations, etc.	• Identify areas where equipment requirements are not met
44. Develop Design Criteria	• Workspace concepts • Console concepts • Control/display/communications concepts • Man-computer interface concepts • Design criteria	• Design criteria	• Equipment production criteria
45. Develop Operational Procedures	• Task-equipment analysis • Operational sequences • Test and evaluation results	• Operational procedures	• Input to operational station book

FIGURE 2

FUNCTIONAL RELATIONSHIPS FOR MIL-H-46855 (ADAPTED FROM GEAR, 1976 AND 1977)




DEMONSTRATION & VALIDATION PHASE
11 ARRANGEMENTS OF STATIONS
17 COMMUNICATIONS CONCEPTS
18 CONTROL CONCEPTS
25 WORKSPACE CONCEPTS
24 ENVIRONMENT DESIGN CONCEPT
STOP
33 TRAINING MEDIA/METHODS
34 PERSONNEL SELECTION REQUIREMENTS
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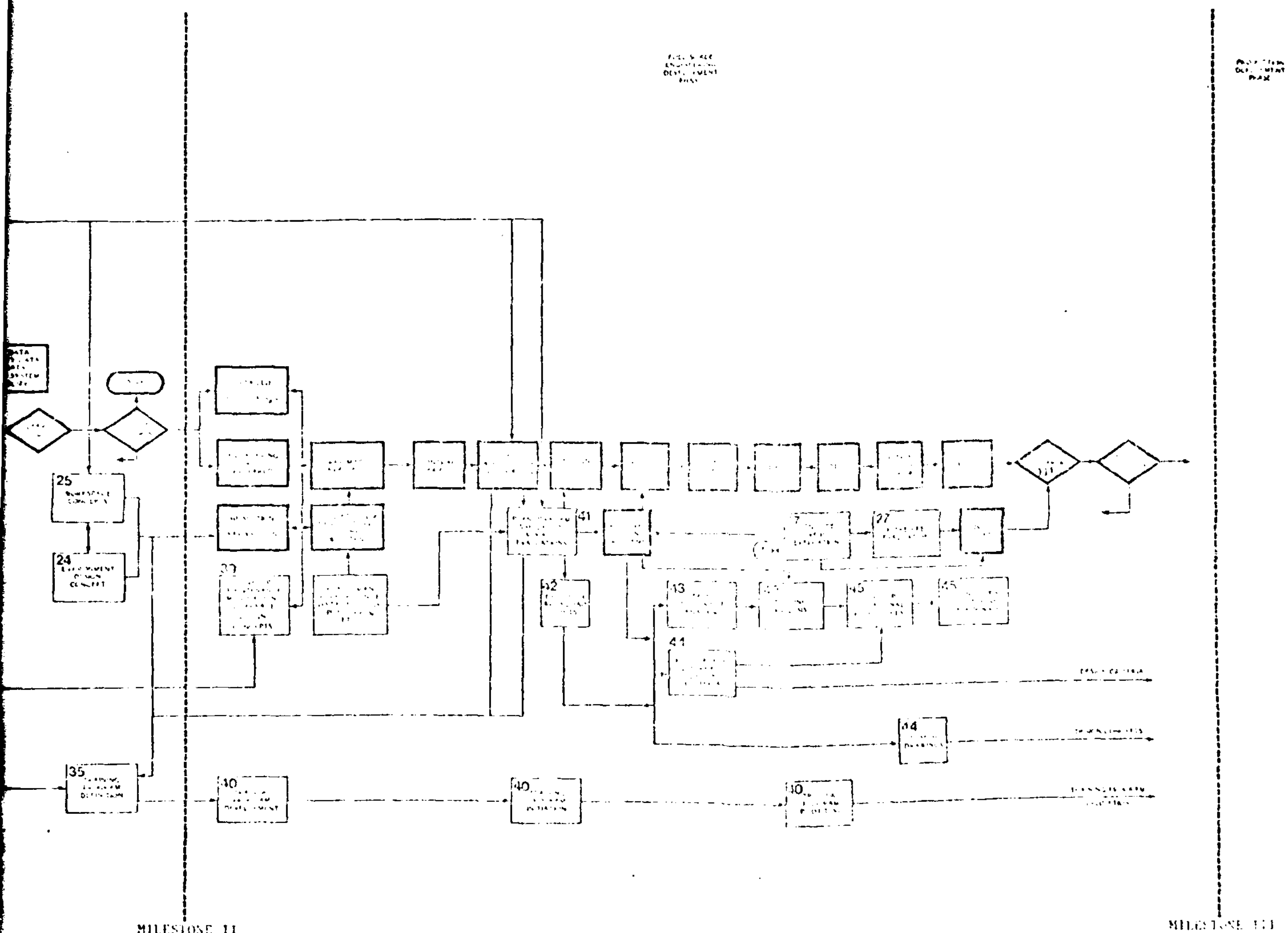

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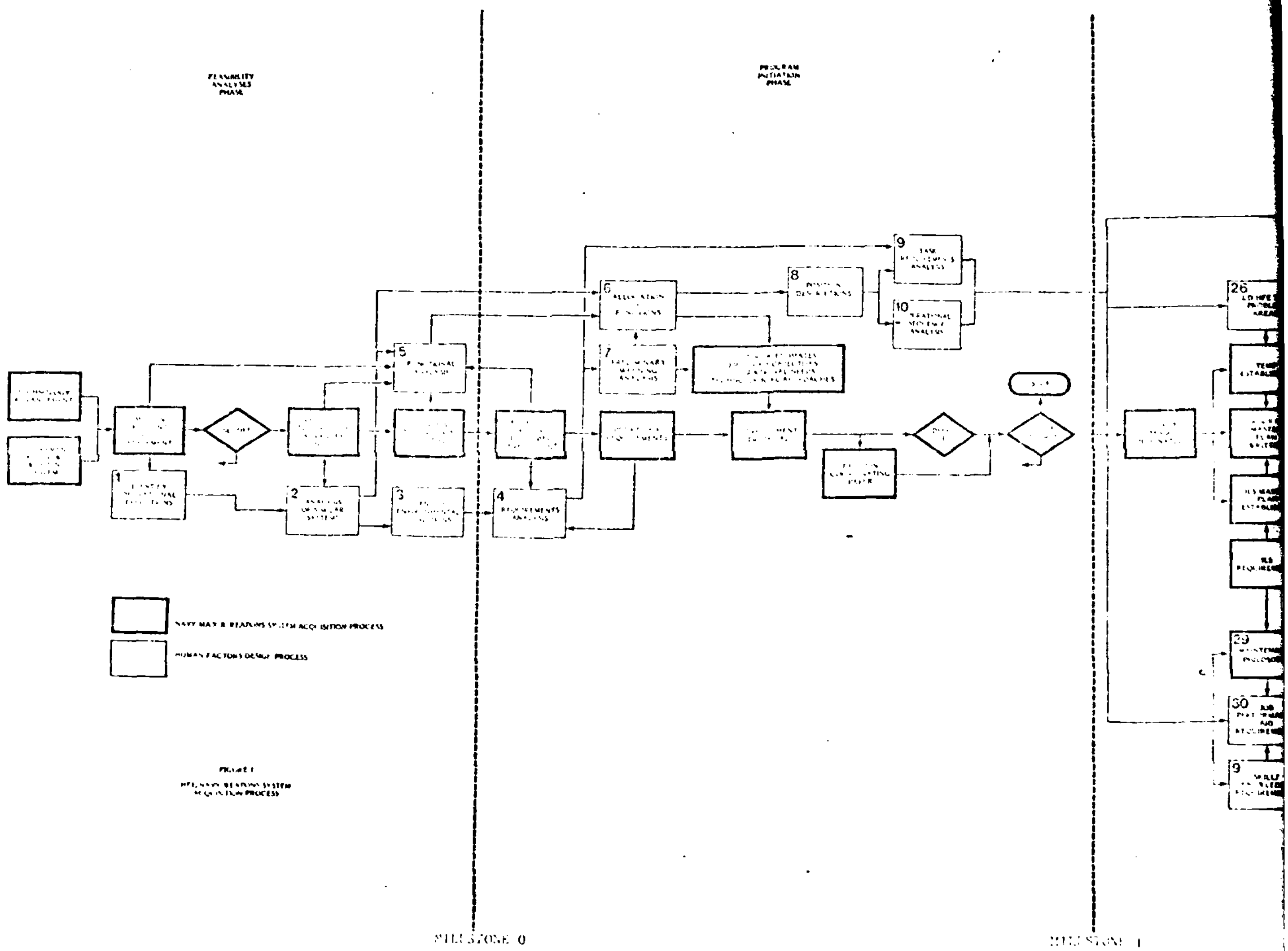
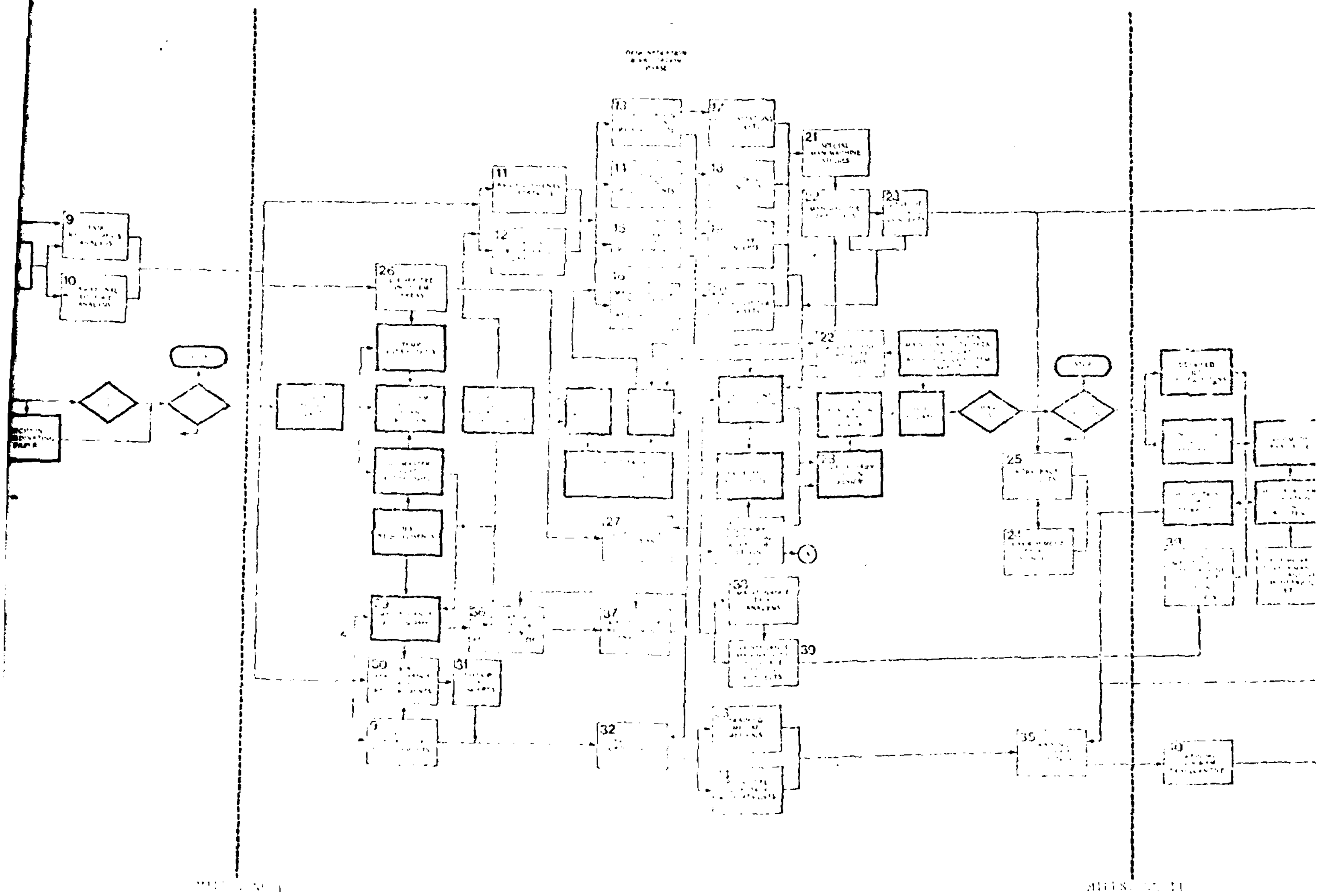


FIGURE 1

HFE NAVY WEAPONS SYSTEM ACQUISITION PROCESS



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2.2.1 Requirements Up to Milestone I

2.2.1.1 Feasibility/Analysis Phase - Summary. In this phase, the major objective and activity is the response to the identification and definition of a mission need. Once a need (mission requirement) has been identified, some exploratory research may be performed in order to develop alternative methods of satisfying the mission requirement. Phase activities and the MENS are evaluated by the SECDEF (Milestone 0) and a decision is made to halt further effort, to require additional mission area analysis, alternate concept development, etc., or to proceed to the next acquisition phase.

2.2.1.2 Feasibility/Analysis Phase - Detailed Discussion. Either a technological development which counters a known threat or the recognition of a tactical threat may initiate the development of a new weapon system. In the first case, the uncovering of improved propulsion systems, sensors, weapons, etc., by industry or government agencies, may initiate the development of a new weapon system which counters a known threat. In the second case, the discovery of combat/weapon systems possessed by potentially hostile forces may be evaluated as a military threat, such that the development of new combat/defensive systems may eventually be called for in order to counter that threat. Tactical threats may be identified by analysis of relative force levels, intelligence information, system/mission effectiveness models, etc.

Mission Element Need Statement

With the identification of a mission need, the MENS is prepared. As called out in DoD Directive 5000.2, the MENS is a required document which is to state:

- Mission area and need in terms of mission tasks to be performed
- Projected threat assessment through the time frame in which a capability is required
- Existing capabilities to accomplish the mission
- Need in terms of existing capability deficiency
- Known constraints to solutions (cost, standardization with NATO, time frames, etc.)
- Impact of lack of capability
- A plan for the identification and exploration of alternative systems

The MENS is essentially a short statement of a present or projected threat and proposed solutions to counter that threat.

The MENS is forwarded to both the Office of the Secretary of Defense (OSD) and the Office of the Joint Chiefs of Staff (OJCS) for review and comments. When the review has been completed, the MENS and comments are presented to the Secretary of Defense.

The SECDEF decision for program initiation is based upon the MENS and attached comments and position papers. The SECDEF's signature (at Milestone 0) initiates the conceptual phase of system acquisition which consists of identifying and exploring alternate solutions to the stated threat.

2.2.1.3 Program Initiation Phase-Summary. Major activities of this phase are: reestablish mission need, survey available technology in order to identify areas of technology inadequacy for proposed systems, begin the definition of an acquisition strategy, and prepare and issue documentation required for the Milestone I decision. The SECDEF decision at Milestone I marks the initial involvement of DSARC. The SECDEF can, at this time, cancel the program, request continued phase activities or begin the Demonstration and Validation Phase.

2.2.1.4 Program Initiation Phase - Detailed Discussion. SECNAV Instruction 5000.1 (which implements DoD 5000.1 for the Navy) states that the conceptual design phase shall be directed towards specifying a broad range of performance and operating characteristics of the system. In beginning the conceptual (program initiation) phase, alternate solutions are developed by the identification of whatever required technology advances are necessary to complete a weapon systems suit. Where technology is insufficient, it is termed a shortfall. A variety of technologies may have to be assessed, including guidance technology, propulsion technology, navigation, etc.

Science and Technology Objectives

Once these technology shortfalls are identified, they are formulated into Science and Technology Objectives (STOs). STOs are statements of capabilities required, but not yet existent, for the proposed combat system. STOs are formulated from previously identified required technological advances and the tactical requirements of the weapon system. These objectives may lead to the upgrading of existing systems or subsystems (radar sensitivity, range, as an example), or complete redesign or development of a system to effect compatibility with the point system.

Preliminary Human Engineering Analysis

Sufficient progress at this point will have been made to initiate a formal Human Factors Engineering (HFE) effort in the system acquisition. This first step, the Identification of Operational Conditions, will serve to familiarize the HFE analyst with the proposed system and will lay a foundation for future HFE analysis. The data collected consists of use and tactical conditions which are expected to be experienced by the weapon system. Use conditions such as:

- Operational modes
- States of readiness
- Modes of communication
- Emergency/contingency condition

may be collected by the HF engineer. Tactical conditions to be identified are:

- Enemy characteristics/capabilities
- Enemy behavior responses
- Own forces characteristics/capabilities
- Own forces behavior/responses
- Own system characteristics/capabilities

This step may serve as the initial foundation upon which subsequent HFE steps may be structured and may suggest the level of effort that will be required to integrate HF in the system design, constraints on human performance, HFE test and evaluation and general planning direction.

Following the identification of operational and tactical conditions, the HF engineer can initiate an analysis of similar systems to be applied at the total system or subsystem level. Of great utility for the HF engineer, this analyses will afford an operational and design baseline from which improvements in the developing system can be made and measured; further, it will point out design problem areas that can be avoided in the developing system.

Systems similarities can extend to:

- Missions
- Operations
- Mission major events
- System functions, etc.

From these similarities, operator and operational data can be gathered, i.e.,

- Functional allocations
- Operational performance histories
- Operational timelines
- Operator workloads
- Human factors design problem identification

The requirement for this step lies in the fact that a great deal of data may (and probably does) exist. These data may be used in nearly all subsequent HF design activities such as functional allocations, requirements analysis, workspace design, etc.

With the review of the MENS by the Secretary of Defense and the establishment of STOs, advanced systems concept development is commenced. Some systems and subsystems will be identified for the combat system and explorations of alternate concepts that will satisfy the STOs continue. Total systems concepts may be available which will show, to some extent, factors defined to greater detail, equipment constraints such as manning levels, and indications of human operator requirements.

Concurrent with advanced system concept development is the HFE analysis of system functions which is a fundamental step in the design process. As the system takes form, an increasingly more detailed description of the system can be established and analyzed. Through this step, functional analysis will:

- Identify missions/mission problems and operations
- Establish mission/operation priorities
- Identify/establish mission/operations major events
- Identify mission functions, subfunctions, etc.
- Analyze system functions and subfunctions,

This material is required for the very basic HFE design steps of functional allocations and procedures generation.

An Environmental Analysis is then performed to identify operational conditions affecting:

- Visibility
- Communications
- Operations
- Safety
- Work performance

The HF engineers must identify these conditions and their potential constraints upon human performance. The HF analyst will design to constraints imposed by the degradation of equipment operation due to environmental factors.

A Requirements Analysis is now performed in which requirements for each function and subfunction by mission and operational conditions are identified. Information requirements for each function are identified which include:

- Information required
- Source of information
- Accuracy requirements

- Currency requirements

Examples of performance requirements identified are:

- Accuracy limits
- Response/performance/completion time limits
- Energy expenditure
- Limits on error rates
- Frequency of occurance

Decision requirements are also identified, e.g.,

- Decisions to be made
- Options
- Decision rules/risks

With the availability of such data as system functions and requirements, environment and operational conditions, an allocation of functions can be performed in which performance of functions is allocated to men or machines, or among different men. Several allocation schemes are usually selected according to such constraints and criteria as:

- Costs
- Convention
- Command decisions
- Relative man/machine capabilities
- Relative man/machine reliabilities
- Operational/engineering complexity
- Level of system automation
- Manpower availability

Operator performed functions are then further allocated to sets of related functions, thereby establishing the rudiments of an individual operator's job. This step is critical to an HFE design process if viable allocation schemes are to be derived. Otherwise, inadequate man/machine and man/man function allocations will degrade system performance.

DSARC Process

Within the time frame of the development of the STOs, the Operational Requirement (OR) is prepared. The OR is a statement of the operational need of the new weapon system and initiates the conceptual effort to meet the stated operational need.

The initial OR may have undefined areas, but is updated prior to the next program decision. Contained in the OR is a cost constraint, a cost target that is estimated to be near that of the actual acquisition. An important aspect of the OR is the establishment of the Developmental Proposal (DP), describing (1) the technical approach which will satisfy the operational requirement. The DP provides alternate approaches and developments that are applicable to fulfilling the OR, (2) an economic analysis and relative benefits of alternate technical approaches; and (3) a recommendation for the technical approach.

In the time frame of the development of the DP, the Decision Coordinating Paper (DCP) is generated. The DCPs principal purpose is to support the SECDEF and Defense System Acquisition Review Council (DSARC) in determining program continuation. The DCP is to contain (as per DoDINST 5000.2):

- An approved MENS
- Information updating MENS
- Alternate program descriptions
- Summary of acquisition strategy
- Short/long term business planning strategy
- Management plan
- Technical risk estimates
- Test and evaluation planning status

The DCP and DP are used by SECDEF and DSARC in rendering all subsequent major milestone decisions. DoDINST 5000.2 details the issues to be addressed at each DSARC decision point; generally these include:

- Reaffirmation of mission need
- Updated threat assessments
- Alternate strategies to be considered
- Operational and logistics considerations
- Acquisition strategies
- Risk estimates
- Test and evaluation master plans (TEMPs)

The DCP is the principle source of these data and, therefore, is updated throughout the weapon system acquisition cycle and reviewed at each DSARC decision point.

At the DSARC I (or Milestone I), the DCP additionally states:

- whether the validation phase is to be entered with

- several system concepts
- a single system concept, or
- involvement of alternate subsystems only, design not to be conducted at the total system level, or

- whether to proceed directly to full-scale engineering development.

At Milestone I the DCP will contain a Technology Assessment Annex (TAA) which identifies areas of technological risks and defines plans for addressing these risks.

At Milestone I, the DCP is forwarded to DSARC for review and action. DSARC recommendations are then forwarded to the Secretary of Defense for final decision. At this point in the HFE design process, system functions have been (and are being) identified and analyzed. environmental conditions identified, similar systems analyzed, preliminary manning estimates made and functions allocated (initially) between men and machines and among operator stations. The operational system is beginning to take form. In order to document, solidify and develop crew requirements, position descriptions are formulated. This generally entails a narrative description of the general duties of a station, i.e., operator roles and responsibilities and operational constraints. Identification of skills and knowledge for each position can be initiated.

HFE Job/Task Analysis

Position descriptions will be used in subsequent analysis to provide a framework from which to develop stations and to modify/document prior efforts.

The individual tasks for each operator are identified (through analysis of tasks and task requirements); in addition, requirements for performing each task are determined. In conducting the analysis, functions are further allocated (or reallocated) to individual operators. Functions become tasks, or are broken down to individual tasks comprising a function, and a sequential task index for each position is developed.

For each task, requirements of the following sort are identified:

- Activity
- Performance time
- Information/communication
- Controls/displays
- Constraints on task performance

Task criticalities and priorities may also be determined in the course of the analysis.

With the availability of functional analysis and allocations, task sequences, and task requirements data, operational sequences between and among operating stations can be

analyzed. In so doing, links between operators and types of links (electronic, verbal, visual, etc.) are identified and the syncronization and phasing of events are examined. These analyses are required in order to examine and evaluate function and task allocations, workloading, operational and communications links, etc.

2.2.2 Requirements to Milestone II

2.2.2.1 Demonstration and Validation Phase - Summary. With the SECDEF's approval to enter this phase, the following has been accomplished:

- Formation of alternate weapon system concepts
- Identification of subsystems targeted for advanced development
- Mission need has been defined
- Acquisition strategies and plans have been developed and approved

The activities and objectives of the demonstration and validation phase are to:

- Conduct preliminary design
- Establish a formal, detailed management plan
- Establish a test and evaluation management plan
- Establish an integrated logistics support plan
- Prepare Requests for Proposals for system/subsystem development
- Construct prototypes of systems and/or subsystems for technical evaluations, and
- Prepare for the Milestone II decision.

2.2.2.2 Demonstration and Validation Phase - Detailed Discussion

Acquisition Management and Planning Policy

In beginning the validation phase, project teams are designated and the Program Master Plan (PMP) is established. This is a basic planning document prepared by the Program Manager (PM) which itemizes the responsibilities of participating organizations (contractors and government organizations). It sets forth plans, schedules, costs and scope of work for each participating organization. Two important considerations of the PMP are test and evaluation plans and integrated logistics support plans.

SECNAV Instruction 5000.1 states: "Integrated logistics support effort shall be conducted as an integral part of the acquisition process and pursued to ensure realistic application of ILS considerations." It further states: "The purpose of ILS is to promote development of hardware which is not only technically excellent, but cost effective, reliable, easily maintained and operated, and able to be realistically supported when

delivered for operational use." As part of the PMP, the Integrated Logistics Support (ILS) Master Plan is established. ILS, as defined by NAVMATINST 4000.20B, is "a composite of all the support considerations necessary to assure the effective and economical support of systems/equipments for their life cycle. It is a integral part of system/equipment acquisition and operation and is characterized by harmony and coherence among all the logistics elements." The principal elements related to the overall system/equipment life cycle, includes:

- Maintenance planning
- Support and test equipment
- Supply support
- Transportation and handling
- Technical data
- Facilities
- Personnel and training
- Logistic support resource funds
- Logistic support management information

The ILS Plan, then, is one in which logistics concepts, techniques and policies are implemented to assure "the effective economical support of a system/equipment during its life cycle and details what ILS tasks are to be accomplished, who is responsible, how they are to be accomplished and when."

Typical elements in the ILS plan are as follows:

- System/equipment description
- The assigned ILS manager
- Management plans
- Personnel and training requirements
- Supply support plans
- Test equipment

About the time of DSARC I, the Test and Evaluation Master Plan (TEMP) has been established. The TEMP is a document prepared by the program manager and is used both as part of the DSARC decision process and as a management plan for Test and Evaluation (T&E). The TEMP identifies the testing to be performed before the DSARC II & III reviews.

Testing is performed on both a component level and a systems level. Component testing consists of demonstration and validation testing of components intraoperability,

maintenance requirements, etc. Systems level T&E consists of Development Test and Evaluation (DT&E) and Operational Test and Evaluation (OT&E). DT&E has as its purpose to:

- Demonstrate that the engineering design is complete
- Demonstrate that design risks are minimized
- Demonstrate that the system meets operational requirements, and
- Estimate military utility of the system when introduced

The level of developmental testing "shall be adequate to ensure: that engineering is reasonably complete; that all significant design problems (including compatability, intra-operability, reliability, maintainability and logistical considerations) have been identified". (DoD INST 5000.3.)

The OT&E serves the purposes of estimating:

- Military utility of the system
- Operational effectiveness, and
- Operational suitability (as in DT&E with the added consideration of training requirements)

and in providing information on organizations, personnel requirements, doctrine and tactics.

<u>HFE Involvement in Planning Policy</u>

With the development of the TEMP, the HFE step to identify HFE T&E problem areas is initiated. This step calls for the identification of areas in which HFE design problems may become evident in the weapon system. These areas are related to performance/system operability, environment, information, communications and manning and training.

The requirements of the step are to: identify potential problem areas in order that the human engineer may specifically address them during equipment design and also to plan formal evaluation of these areas as part of the test and evaluation process. The results of this step can be formulated into several test requirements and input to the Test and Evaluation Master Plan (TEMP), thereby incorporating HFE into the overall test plans. A further result of this step is the development of an HFE Test and Evaluation Plan which will:

- Itemize HFE issues to be tested
- Identify areas where specific issues will be emphasized in testing
- Provide test schedules

As ILS plans and requirements are developed and defined, the maintenance philosophy of the weapon system will evolve. The maintenance philosophy should cover such areas as overhaul cycles, levels of organizational or depot repair, system performance monitoring schemes, training and test equipment, standardization of components, planned and corrective maintenance schemes (remove and replace, remove, repair and replace).

NAVMAT Instruction 4000.20B calls for a level of repair (LOR) analysis to be made for all Naval material being acquired for the operational inventory. LOR analysis is defined as an economic and non-economic evaluation used to establish the maintenance level at which an item will be replaced, repaired or discarded. Non-economic LOR criteria are cited as being:

- Safety
- Vulnerability
- Survivability
- Mission success
  - criticality
  - effectiveness
- Manning
- Human Factors
  - special skills
- Deployment mobility
- Policy (specifications)
- Technical feasibility of repair
- Special transportation factors

These data can be used to identify the roles of maintenance technicians for each maintenance function, therein providing necessary information for developing maintenance JPA concepts, performing requirements analysis, task analysis and for training system development.

Initial Training System HFE Requirements

Data from the Task Requirements analysis, operational sequence analysis, maintenance philosophy are used to identify job performance aid (JPA) requirements. This step represents the first effort towards the development of the training program for the weapon system.

Several steps are involved in determining JPA requirements:

- Identify the information to be conveyed
- Identify information type

- procedural (operational or maintenance)
- instructional
- computational
- decision making

- Identify characteristics that affect JPA requirements
- Identify those units or sequences of information that are best learned or presented by JPAs

The JPA/training decision is made (in part) by the identified characteristics of the tasks or information to be learned, i.e., ease of learning, requirements for branching steps, number of similar tasks, frequency, etc. For example, for infrequently required tasks that require a great many branching/decision steps, JPAs are called for, but for frequently required and easily learned tasks, training is a more appropriate tool.

This JPA/training decision leads to the development of JPA concepts, the identification of skill/knowledge requirements, training objectives, etc., and greatly facilitates training program definition and development. JPAs can then be developed by first identifying constraints and developing concepts involving:

- Computer-generated displays
- Manuals
- Special guides

Feasible concepts can then be selected for trade-offs.

Performed concurrently with the identification of JPA requirements is an analysis of required skills and knowledges which will provide the Human Factors Engineer with data concerning the number and complexity of skills required and the magnitudes of knowledge requirements. Skill requirements for each position are assembled according to skill levels required, performance standards, criticality and similarity to other skills. Knowledge requirements for each position are assembled by type (diagnostic, procedural, etc.), learning difficulty and criticality.

Initial HFE Maintainability Design Requirements

Upon the identification of a maintenance philosophy, requirements for maintenance functions can be identified and formulated into Operator/Maintainer Roles and Responsibilities. Planned Maintenance (PM) activities such as checkout (static and dynamic), cleaning, removal and replacement, etc., and Corrective Maintenance (CM) activities, such as fault detection, troubleshooting, repair, calibrations, etc., can be identified and classified according to maintenance functions.

A further HFE design step is the performance of a Maintenance Requirements analysis. In this step the Human Factors Engineer will analyze maintenance requirements

to electrical components using: Failure Modes and Effects Analysis (FMEA) and LOR data, component design requirements and a selected maintenance philosophy. The analysis also entails identifying and analyzing information requirements for each maintenance function, identifying and analyzing accessibility requirements, tool and test set requirements and design requirements. This step, once completed, will be used to perform a Maintenance Task Requirements Analysis and to develop maintenance man/machine design concepts. The Maintenance Task Requirements Analysis requires that components and maintenance activities be identified and maintenance functions and tasks be developed. Once this is completed, tasks and functions are analyzed and reduced to task elements.

Tasks and task elements are sequenced and analyzed for branching steps. Task requirements are identified along dimensions such as:

- Estimated time to perform
- Information/communications
- Control capabilities
- Display capabilities
- Display indication/information
- Equipment design features
  - space for accessibility
  - built in test points
  - tool interfaces
  - safety provisions
- Skill/knowledge
- Constraints on task performance
- Frequency of task performance
- Impact of error

Task criticality and priority are also identified.

Maintenance Man-Machine Interface concepts are developed by analyzing maintenance activities in order to identify:

- Design of equipment man/machine interfaces (controls/displays, consoles, handles and handholds, labels and markings, packaging, optics, etc.)
- Design of information displays (display formats, JPA's, diagnostics, etc.)
- Maintenance schedules (Planned Maintenance (PM), and Corrective Maintenance (CM))

Also examined are maintenance workspace layout and arrangement effects by considering such maintenance aspects of workspace dimensions, equipment arrangement, maintenance support requirements, equipment/compare and accessibility, etc.

Maintenance conditions may also be identified along such dimensions as maintenance environment (illumination, temperature and humidity, etc.) and operational conditions such as states of readiness, emergency, blackout, etc. Maintenance personnel requirements are examined along issues of manning (levels, personnel ratings) procedures (PM and CM) and automation levels (automative checkout, manual checkout, etc.). Maintenance training requirements need to be identified in terms of skill and knowledge required at exit of training, entry skills and knowledge; school training, JPA or OJT trade-offs, training media and methods and course development and implementation.

Operational sequence and task requirements data are used in the determination of station arrangements, requirements and workspace layouts.

<u>Preliminary HFE Design</u>

Spacial station arrangements are derived in order to facilitate the minimum required traffic, information and communication flows. Review of the requirements analysis, operational sequence analysis, task requirements and functional allocations provide the necessary information to generate Station Arrangement Schemes. Factors to be considered are: constraints on the spacial distribution of stations, requirements for traffic flow, requirements for information flow, and required communications links between stations. A link analysis is often performed to identify and analyze required links between stations; operational sequence data provide information concerning the type of links (verbal, electrical, etc.) between stations and requirements for traffic flow. With these data, arrangement schemes can be generated.

In selecting or developing various station layout concepts, a list of items to be considered is established (available space, communications requirements, etc.). These factors will be differentially weighted in selecting or developing arrangements.

Station workspace layouts and arrangement of stations are typically determined concurrently. Generating workspace layouts requires that the following requirements are either determined or identified from previous analyses:

- Station manning
- Control functions
- Display functions
- Communications functions
- Equipment
- Environmental
- Visual and reach envelopes

With these kinds of data available, individual station locations and orientations can be formulated as concepts. In order to evaluate these concepts, criteria are developed. OSD data, task requirements, control and display requirements, etc., are reviewed for applicability to station layouts, and criteria are formed and weighed. Alternate concepts are then selected and modified until an optimum workspace layout scheme is devised.

At this point in the HFE Design Process, the controls, displays and communications requirements for each station are identified. Available data covers the allocation of functions, task requirements analysis and operational sequence analysis.

For those operator allocated system functions, the characteristics of control functions must be identified, enabling individual control requirements to be identified. For each task, control requirements such as type of action (continuous or discreet), criticality, expected frequency of use, precision requirements for continuous controls and required feedback information are identified.

Requirements for individual displays are similarly identified, per task, along dimensions such as the information to be displayed, information type (continuous or discreet real time or history, status or performance), criticiality or importance, associated controls, update rate, duration of information presentation, and accuracy requirements.

Communications requirements, per task, are identified along such dimensions as reporting requirements (frequency, urgency, system status, etc.), standard messages, information dissemination and number of stations reporting and/or receiving information.

In recent years, computers have been used in the generating of displays, aiding troubleshooting and logistics, training systems, the actual control of system functions and the storage, retrieval, analysis and dissemination of tactical data. Therefore, formal HFE analysis of man/computer interfaces is required. This step, within the HFE design process, identifies interface requirements by specific functional areas, such as: monitoring, verifying, configuration change/setup; override; programming; debugging; data entry; mode selecting; data maintenance analysis and dissemination; and display status and projections.

For tasks assigned to the above functional areas, identification is made of:

- Required information
- Required control actions
- Decisions
- Feedback
- Data processing information

- Criticality
- Control and display requirements

Concepts for controls, displays and communications are developed by first identifying constraints such as cost, conventions, available technology. Panel concepts can be generated using different types of controls and displays, communication systems, man/machine functional allocations, and arrangements and are based in part on human factors design criteria such as importance, sequence of use, and frequency of use. For each concept generated, link analyses and error likelihood analyses may be performed to identify potential performance problems for each candidate concept. Console and panel arrangements can be further analyzed by the establishment of two and/or three dimensional models of each concept, enabling the selection of feasible panel concepts for trade-offs.

In developing man/computer interface design concepts, identification is made of constraints such as:

- Input/output modes and requirements
- Message formats
- Continuous versus call-up display
- Override
- Display symbology
- Program selector

Once constraints and requirements are identified, overall man/computer interface concepts can be generated, and feasible concepts selected for trade-offs.

HFE Training System Design

Training goals are identified by first developing behavioral objectives for identified tasks and then assigning specific tasks to pertinent behavioral objectives. Performance conditions and standards then are identified for each objective.

Training media and methods are selected by identifying course requirements such as content, phasing, level of detail, test and instructor requirements. After reviewing constraints and factors to be considered in selecting a training method, factors can then be weighted for importance and a training method selected.

Media selection will be determined by the following:

- Training objective priorities
- Requirements for
  - visual presentations of information

- motion representation
- sound representation
- branching
- prompting and cueing
- simulation

Throughout the validation phase, systems are identified for advanced development. As these systems are selected, requests for proposals are prepared for engineering developments of subsystems and components. Solicitations for limited production of some items may also be advertised. As contractors for subsystem and component engineering development and prototyping are let, the Test and Evaluation plans are implemented.

Input to subsystem design are data available from HFE efforts performed to date. Principal inputs are the results of maintenance man/machine interface requirements and control console concepts.

HFE Workspace Concepts

Man-machine trade-off criteria for controls, displays and communications typically are functions of operability dimensions, and equipment reliability and cost (life cycle and acquisition). Operability (or human performance) dimensions such as: error likelihoods, response and performance times, operational complexity, training time and requirements, skill requirements, workloads, HFE design principles, maintenance requirements and safety are formulated into man/machine trade-off criteria. Requirements for additional data such as:

- Relative man/machine capabilities
- Relative effectiveness of man vs. machine operation
- Operational procedures
- Workloads
- Skills

are first identified, and a study test plan developed. Requirements for mock-ups, scene generators, simulators, measurement apparatus, etc., are identified prior to test setup and selection of test subjects. Studies can then be conducted, the data analyzed and interpreted, and results inputted to trade-off criteria. With these criteria available, trade-offs are performed according to trade-off method selected, criteria weights, ratings of alternate concepts in terms of conformity with criteria, and the integration of weights and rating for each alternate man/machine concept.

Console concepts are generated by an examination of control, display, communications and man/computer interface concepts as well as operational sequence data, JPA

concepts, man/machine trade-offs and HFE data and principles. Specifically addressed is the development of panel specifications (i.e., size, shape, orientation, color), control and display specifications (types, sizes, shapes, colors, locations, detents) and arrangements, communications specifications (messages, modes, etc.) and man/computer interface specifications.

Workspace and environmental design concepts are formulated using data such as:

- Equipment requirements at each station
- Environmental affects at each station
  - illumination
  - atmospheric conditions
  - noise and vibration limits, etc.
- Operational requirements
- Maintenance

Workspace concepts are then generated according to controlling constraints, requirements, and environmental effects.

Milestone II Decision

Prior to DSARC II (Milestone II), the DCP is updated to contain firm program schedules, cost and information schedules. The DCP is forwarded for comment to the Defense Acquisition Executive who coordinates the review activities with the OSD and OJCS. The DCP and comments are then forwarded to DSARC for recommendations. The DSARC II (Full-Scale Engineering Development) recommendations are to be made in accordance with the following Program Issues (as per DoD 5000.2):

- Mission element need is reaffirmed and the threat updated
- The system meets mission element needs
- NATO standardization requirements are satisfied
- System trade-offs have produced the optimum balance in cost, performance and schedule
- Risks have been identified and are acceptable
- Planning for selection of major subsystems is clearly stated
- Testing and evaluations have been completed and results support recommendations
- The TEMP identifies and integrates the T&E to be accomplished prior to DSARC II and III

Once DSARC has reviewed the above, recommendations are forwarded to the Secretary of Defense for approval to enter the full-scale engineering development phase.

2.2.3 Requirements to Milestone III

2.2.3.1 Full-Scale Engineering Development-Summary. During this phase, detailed ILS specifications are generated, the Request for Proposals for the weapon system is written, full-scale engineering development of the system is completed, preparations for production are made, test and evaluation is continued and preparations are made for the Milestone III decision. The DSARC process continues and the SECDEF decides either to continue full-scale engineering development, cancel the program or enter the Production and Deployment Phase.

The primary purpose of this phase is "to ensure completion of sufficient effort to permit a confident commitment of resources required for quality production" (SECNAVINST 5000.1). This phase marks the beginning of the preparation of contract bid packages. Drawings, specifications and plans are collected for incorporation in the RFP. A Human Factors Engineering section of the RFP may include requirements for incorporating and/or developing equipment designs, crew complement and operator roles. The RFP then would include HFE Data Item Descriptions (DIDs) which state HFE which state HFE documentation requirements for the weapon system procurement.

2.2.3.2 Full Scale Engineering Development - Detailed Discussion. According to Geer (1976), the decision to use or not to use certain DIDs depends upon factors such as:

- The extent to which the PM wishes to ensure performance and documentation of HFE analysis
- Cost of redundant/unnecessary analysis data
- Scheduling

Geer proposed that existing HFE DIDs be modified and proposes three relevant to:

- Mission Analysis Report
- Functional Allocation Report
- Task Analysis Report

After contracts have been awarded, the major activities include combat system design and integration of subsystems, conduct of design reviews, equipment prototyping, system testing and preparation for DSARC III.

Involvement on the part of the Navy is limited during this phase, essentially being limited to preparation for, and conduct of, Test and Evaluation, preparing for the impending Milestone III decision and monitoring contractor activities.

HFE Issues During Full Scale Engineering Development

Human factors requirements turn from an analytic and design emphasis towards highly formal design evaluations, and design criteria and procedures development.

Simulations and mock-up evaluations are required as part of the HE effort in order to:

- Identify design problems for HFE inputs for design reviews
- Conceptualize, document and verify design concepts
- Collect data for workload, timelines, procedures, etc.
- Identify areas where redesign may be required
- Develop design criteria

The level of sophistication in a mock-up evaluation depends largely on the complexity of the system and the number and magnitude of design issues to be examined. With major weapon systems development, this level of sophistication is typically high. Full sized, functional mock-ups, or if sophisticated enough, simulators, are required. Detailed evaluations reveal:

- Operator/crew workload
- Analysis of procedures
- Man-machine interface analysis, etc.

and can resolve design issues, e.g., where space limitations in a workspace are severe, simulations will indicate design criteria along operability/maintainability dimensions where implementation of military standards (MIL-STD-1472, for example) are clearly impossible. Man-in-the-loop simulations are also implemented to evaluate training systems and maintainability design.

The major considerations of mock-ups and simulations is that of fidelity. The additional experimental control that is afforded by mock-ups and simulators is offset somewhat by the degree to which the simulation can approach authenticity of the actual equipment and environment.

Based essentially on simulations and mock-up evaluations, workload limits at points within the mission scenario are identified, analyzed and inputted to detailed design criteria development.

3.0 HFE TECHNOLOGY REVIEW AND ASSESSMENT

3.1 HFE Technologies Applicable During Feasibility And Program Initiation Phases

Mission Analysis

Geer (1976) states that Mission Analysis "is the first step in the system development required for the establishment of human factors design criteria".

For the human factors specialist, the analysis will be useful in subsequent analytic techniques such as analysis of similar systems, environmental analysis, functional analysis, requirements analysis, operational conditions, and functional allocations. Mission analysis will also provide the analyst with:

- An understanding of the mission
- Identification of mission phases
- Mission accuracy requirements
- Mission timing, information, urgency, etc.

Geer points out factors to be considered in establishing Mission Scenarios and Mission Profiles. Selected Mission Scenario factors are as follows:

- Assumed operational factors
- System and subsystem proposed capabilities
- Postulations of geographic positions
- Mission starting points (time and location)
- Potential deviations from established mission problem
- Development of alternate profiles based on threat detectors
- Development of target identification techniques
- Target engagement techniques
- Evasive maneuvers

In performing mission analysis, the above factors are identified (from MENS, relative force levels, etc.). Mission milestones are identified (e.g., reach cruise altitude) and can be used to segment the total mission. For each mission segment, identification of factors relevant to the mission segment can be made.

These data, once gathered, are then formulated into a narrative describing the mission. For some weapon systems, a variety of missions may be undertaken (surveillance, surveillance/attack, attack) and a mission profile and scenario for each will be created in performing Mission Analysis.

Functional Analysis

Functional Analysis is the identification and analysis of broadly defined operations which contribute to a system mission. The following five steps are sufficient to perform the analysis:

- Identify mission and operations, and for each identified, determine any:
  - constraints on function performance
  - requirements for function performance
- Prioritize missions and operations by:
  - frequency of occurrence
  - performance times
  - criticality to total mission
  - difficulty
- Identify major mission events
- Identify system functions relevant to mission phases and operations
- Analyze functions
  - functional sequences
  - functional dependencies
  - constituent subfunctions

Initially, the functional analysis is a simple restatement of mission analysis. As subsystems are proposed or chosen to satisfy mission requirements, the analysis is iterated and functions are determined and analyzed at greater and greater levels of detail.

Systems Analysis and Integration Model (SAIM) (Malone, 1967) is a method to collect and present systems function and requirements information. A matrix is used to classify the information into three categories:

- Systems determinants - nature and structure of the system
- System components - represents systems parts
- System integrations - integrates the components into the overall system

The matrix is generated by listing in both the rows and the columns the identified system determinants, components and integrations (Figure 4). The appropriate cells of the matrix are checked in order to identify where column entries are associated with row entries.

A method for analyzing functions is the Functional Block Diagram (FBD) (also known as Functional Flow Diagram). This is performed (typically) by the following steps.

- Formulate functions into a sequential flow
- Develop second level functions based on top level functions, mission requirements and functional analysis.

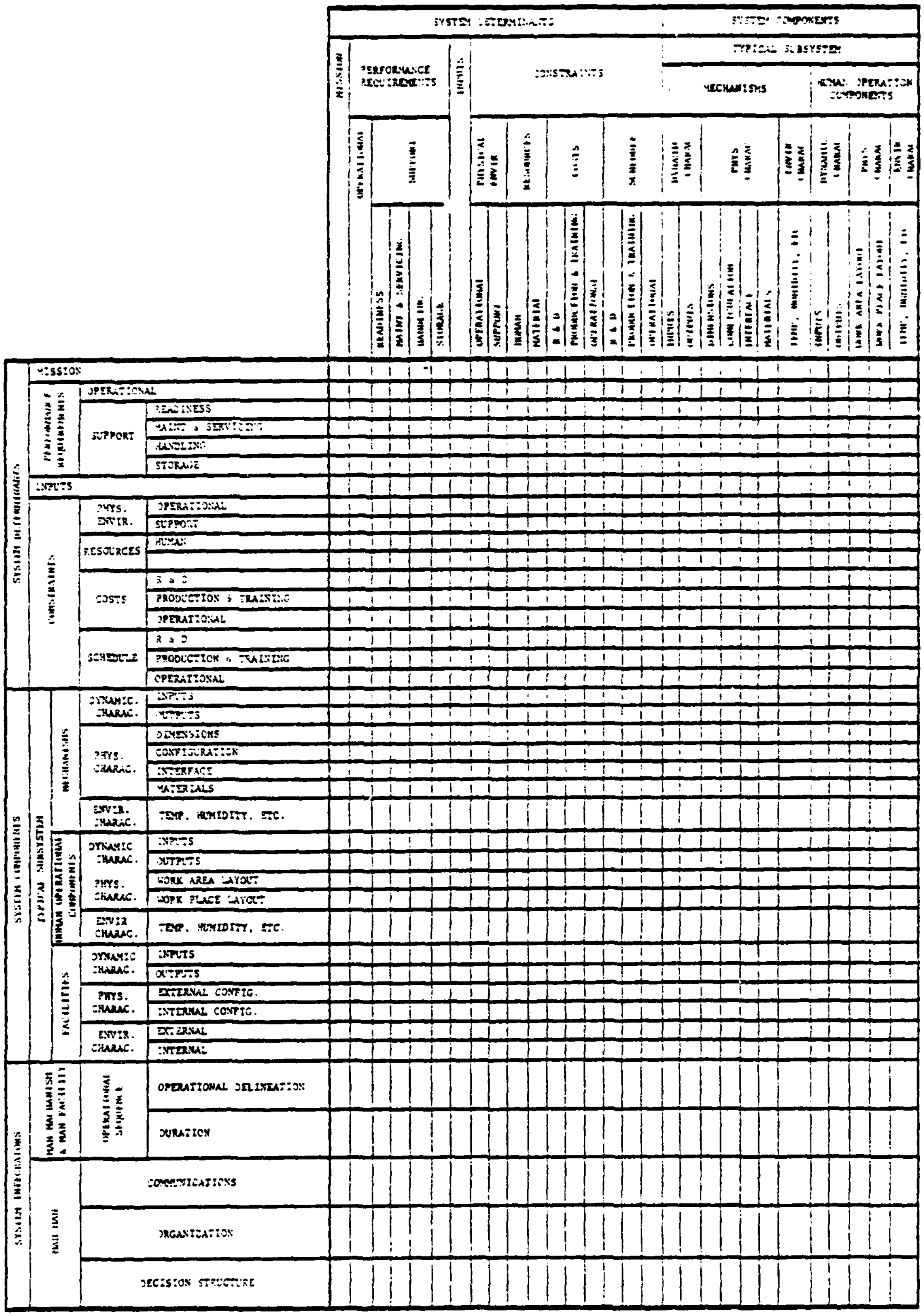


FIGURE 4
SYSTEMS ANALYSIS AND INTEGRATION MODEL (SAIM)

- Iterate until a level of detail is evident to determine how a function is to be performed

Two examples of Functional Block Diagrams are presented in Figures 5 and 6.

The utility of the Functional Block Diagram for the human engineer is to provide a detailed sequence of mission/equipment events, a sequential outline of system requirements, and inputs to subsequent HFE activities such as:

- Functional allocations
- Operational sequence analysis
- Task analysis
- Timeline analysis
- System requirements analysis

Environmental Analysis

Based on mission analysis data, an Environmental Analysis can be performed in order to identify conditions affecting operational issues such as visibility, communications, performance and safety. Environmental considerations such as:

- Time of day
- Glare
- Illumination levels
- Atmospheric conditions
- Weather conditions
- Noise
- Vibration
- Acceleration or sea state
- Shock
- Temperature

for each mission and mission phase of the weapon system are identified and become "design to" criteria and considerations in requirements analysis.

Requirements Analysis

A Requirements Analysis is applied to determine information, performance, decision and support requirements for each function identified. As applied, the analysis usually entails identifying and listing requirements for each function identified. Information requirements include: source, accuracy and currentness. Performance requirements include: accuracy, time limitations to perform/complete, error limits, frequency of

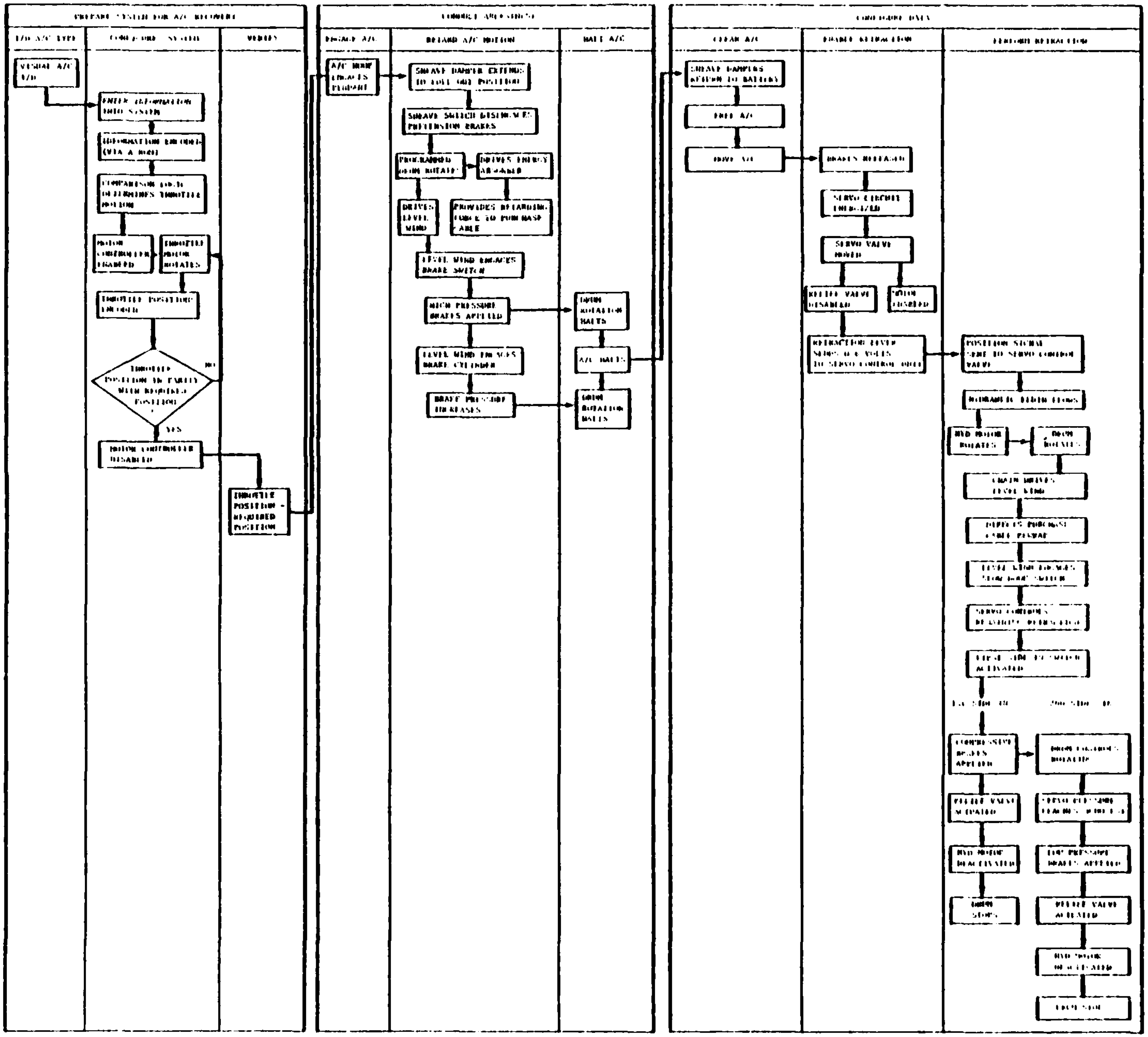


FIGURE 5
THREE-LEVEL FUNCTIONAL BLOCK DIAGRAM

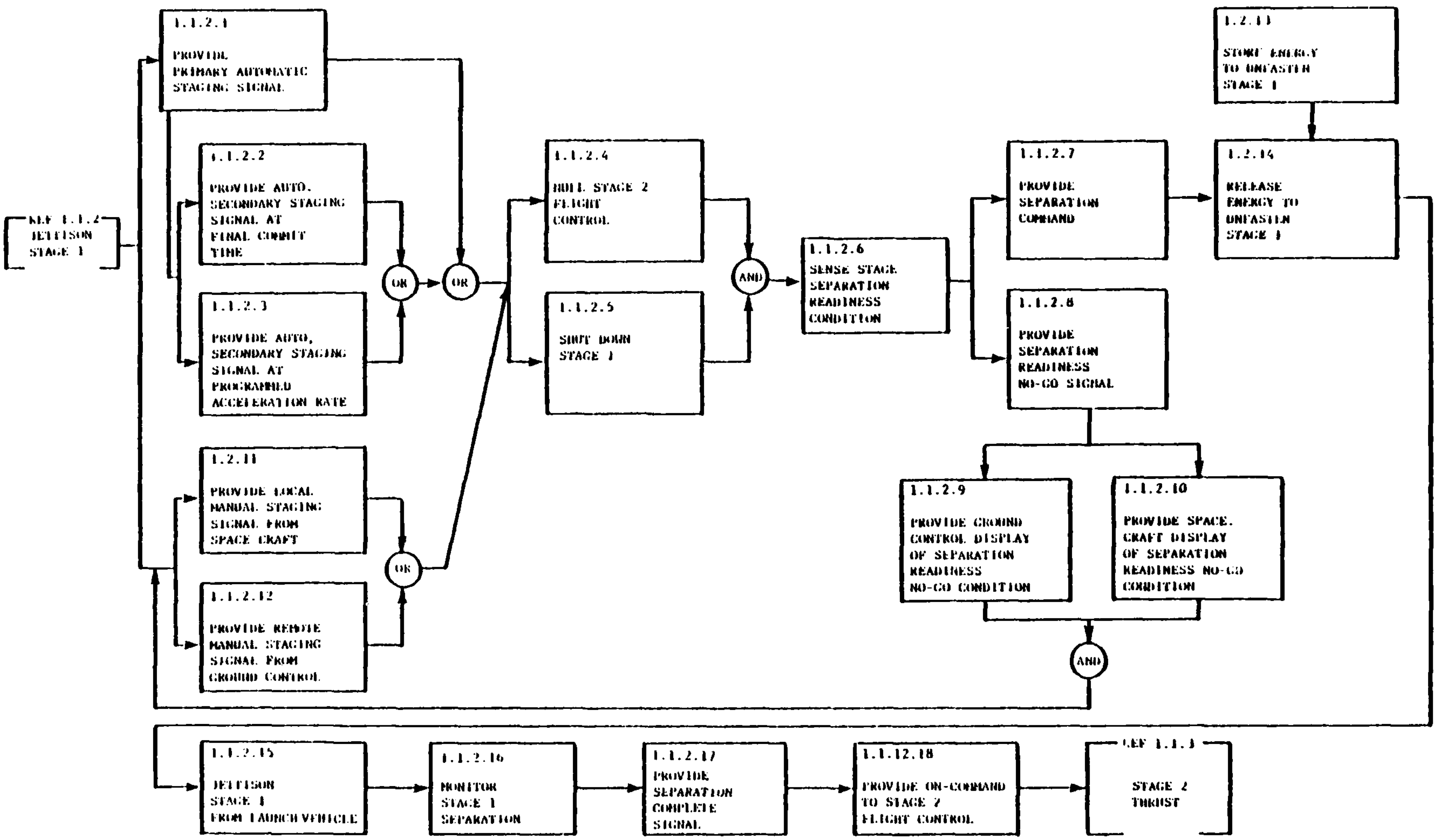


FIGURE 6
FUNCTIONAL FLOW BLOCK DIAGRAM - THIRD LEVEL

occurrence, energy expenditures. Decision requirements such as options, rules and error tolerances are also identified. These data serve as factors to be considered in functional allocations, task analysis, communication, control and display requirements identification. Mission scenarios and profiles are the principle data sources for the analysis. An example of a performance requirements analysis data collection form is presented in Figure 7.

Functional Allocation

Within the Navy (and other military services), manpower issues (personnel types and availabilities) are receiving increasingly greater attention. A Navy program, "Military Manpower Versus Hardware Procurement" (HARDMAN), has recently been initiated which will attempt to integrate manpower requirements throughout the weapon system acquisition process, and also to provide hardware/manpower tradeoff guidance as an integral aspect of system design (Boneau, 1979). A major aspect of HARDMAN implementation is the assessment and development of Human Factors Engineering, Training and Manpower Planning technologies. In fact, a driving force behind HFE technology development (particularly, evaluative and man-machine tradeoff (allocation) technologies) is the HARDMAN program, and that HARDMAN technology development emphasizes evaluative and tradeoff technology which is highly consistent with A-109 and current acquisition strategy.

With the availability of data from the functional analysis, requirements analysis and analysis of similar systems, function allocation schemes can be formulated and evaluated. The principal steps taken in allocating functions are to:

- Identify constraints on allocation (convention, cost);
- Identify or estimate level of system automation;
- Identify functions best performed by men or machines; and
- For functions allocated to men, establish a taxonomy of related functions.

A variety of techniques are available to perform these steps. One technique called the Evaluation Matrix (Geer 1976) uses sets of criteria for functional allocation. Examples are:

- Cost (acquisition and life cycle)
- Response time
- Error rate
- Reliability
- Survivability

FIGURE 7
FORM FOR COLLECTING PERFORMANCE REQUIREMENTS

Function ____________________

Accuracy Requirement	Time Limits	Error Limits	Frequency of Occurance	Energy Expenditures	Special

Criteria are weighted and man vs. machine allocations are scored (on a scale) for level of agreement of the criteria. An example of an evaluation matrix is present in Figure 8 (adapted from Geer, 1976).

Another technique is the use of a Relative Capabilities List (Table 2 as an example). In this technique a function to be allocated is compared to the list and the analyst determines (more or less subjectively) the mode of functional performance (man or machine or both), in accordance with the degree to which a function is most suited to man or machine performance.

The Computer Aided Function-Allocation Evaluation System (CAFES) (Edwards, et al, 1976, Whitman, 1974, Geer 1976, Anderson, 1974) provides a means to evaluate functional allocation schemes. This capability is provided by one of CAFES five submodels, the Functional Allocation Model (FAM). The remaining CAFES submodels are:

- Data Management System (DMS)
- Workload Assessment Model (WAM)
- Computer Aided Crew Station Design Model (CAD)
- Crew Station Geometry Evaluation Model (CGE)

Since CAFES is intended to be a comprehensive tool implemented throughout a systems development cycle, CAD, WAM and CGE will be discussed at those points where their application is most suitable, leaving the present discussion to DMS and FAM.

DMS provides baseline data for all other CAFES subsystems and has three purposes:

- Data maintenance (input, editing, storage)
- Interfaces with the other submodels (in terms of data transfer)
- Output data direction

DMS is comprised of four different modules:

- Editor - stores, inputs and edits data
- User interface - accepts directions for data manipulation
- Executive - implements other submodels and prepares data files
- Report generator - directs output as specified by the user

DMS is essentially the medium by which a CAFES user implements the other submodels and maintains a system data base.

FAM is designed to:

- Identify and organize system functions
- Analyze and rank order various functional allocation schemes

HYPOTHETICAL TRACKING FUNCTIONS	INHERENT OPERATOR CAPABILITIES					INHERENT EQUIPMENT CAPABILITIES			TOTAL SCORE		PROPOSED ALLOCATION			
													MACHINE	
	DETECTING SIGNALS IN THE PRESENCE OF HIGH NOISE ENVIRONMENT (X5)	RECOGNIZING OBJECTS UNDER VARYING CONDITIONS OF PERCEPTION (X4)	HANDLING UNEXPECTED OCCURENCES OR LOW-PROBABILITY EVENTS (X4)	REASONING INDUCTIVELY (X1)	PROFITING FROM EXPERIENCE (X2)	RESPONDING QUICKLY TO SIGNALS (X3)	PERFORMING PRECISE ROUTINE REPETITIVE OPERATIONS (X2)	COMPUTING AND HANDLING LARGE AMOUNTS OF STORED INFORMATION QUICKLY AND ACCURATELY (X4)	OPERATOR	MACHINE	OPERATOR	BOTH	EQUIPM'T	SOFTWARE
DETERMINE IF TARGET TRACKS IN SYSTEM	25	8	12	3	6	9	8	4	81	41	X			
ACTUATE SEQUENCE	5	4	4	1	2	3	2	4	20	24		X		
PUT NEXT TARGET IN TRACK LIST UNDER CLOSE CONTROL	5	4	4	1	2	9	10	4	21	43			X	X
ADVANCE HOOK ON DISPLAY TO TRACK COORDINATES	5	4	4	1	4	9	10	4	21	43			X	X
DETERMINE IF TARGET VIDEO PRESENT	20	8	8	3	4	9	8	4	70	39	X			
DETERMINE IF HOOK LINES UP WITH PRESENT TARGE POSITION	20	8	8	3	6		8	4	73	40	X			
ETC.....														

FIGURE 8
EVALUATION MATRIX FOR FUNCTIONAL ALLOCATIONS
(Geer, 1976)

TABLE 2
RELATIVE CAPABILITIES LIST

MAN	MACHINE
Can monitor low probability events not feasible for automatic systems because of number of events possible	Limited program complexity and alternatives; unexpected events cannot be handled adequately
Absolute thresholds of sensitivity are very low under favorable conditions	Generally not as low as human thresholds
Can detect masked signals effectively in overlapping noise spectra	Poor signal detection when noise spectra overlap
Able to acquire and report information incidental to primary activity	Discovery and selection of incidental intelligence not feasible in present designs
Not subject to jamming by ordinary methods	Subject to disruption by interference and noise
Able to recognize and use information, redundancy (pattern) of real world to simplify complex situations	Little or no perceptual constancy or ability to recognize similarity of pattern in spartial or temporal domain
Reasonable reliability in which the same purpose can be accomplished by different approach (corollary of reprogramming ability)	High reliability may increase cost and complexity; particularly reliable for routine repetitive functioning
Can make inductive decisions in new situations; can generalize from few data	Virtually no capacity for creative or inductive functions
Computation weak and relatively inaccurate; optimal game theory strategy cannot be routinely expected	Can be programmed to use optimum strategy for high-probability situations
Channel capacity limited to relatively small information throughout rates	Channel capacity can be enlarged as necessary for task
Can handle variety of transient and some permanent overloads without disruption	Transient and permanent overloads may lead to disruption of system
Short term memory relatively poor	Short term memory and access times excellent
Can tolerate only relatively low imposed forces and generate relatively low forces for short periods	Can withstand very large forces and generate them for prolonged periods
Generally poor at tracking though satisfactory where frequent reprogramming required; can change to meet situation. Is best at position tracing where changes are under 3 radians per second	Good tracking characteristics over limited requirements
Performance may deteriorate with time; because of boredom, fatigue, or distraction; usually recovers with rest	Behavior decrement relatively small with time; wear maintenance and product quality control necessary
Relatively high response latency	Arbitrarily low response latencies possible
Relatively inexpensive for available complexity and in good supply; must be trained	Complexity and supply limited by cost and time; performance built in
Light in weight, small in size for function achieved; power requirement less than 100 watts	Equivalent complexity and function would require radically heavier elements, enormous power and cooling resources
Maintenance may require life support system	Maintenance problem increases disproportionately with complexity
Nonexpendable; interested in personal survival; emotional	Expendable; non-personal; will perform without distraction

- Analyze and output data for the preparation of Operational Sequence Diagrams

Input data for using FAM suggest its complexity and comprehensiveness, e.g.:

- Action mode (channel activity, tactile, visual)
- Average operator reliability for a nominal task time
- Earliest task start time during a mission
- Task reexecution time for interrupted tasks
- Latest tasks start time
- Machine reliabilities
- Mission objectives (e.g., target acquisition) consisting of series of dependent tasks
- Mission scenario tasks (time based)
- Mission start time
- Mission stop time
- Mission time
- Scenario events
- Nominal task execution times
- Number of task repetitions
- Operator reliability (per task)
- Task priority (task interruptability)
- Reliability curve data
- Task reliability weights (relates task importance)
- RNO - Remaining Number of Opportunities to execute a task (as a function of time units until latest start time
- Pulse constraints (precedents to task execution)
- Situations during mission (equipment malfunction, etc.)
- Task names
- Task allocations
- Task classification (monitor, operate, etc.)
- Task number (for user identification)
- Task load rating (sum of ratings of criticality, interruptability, reliability, precision and concentration)
- Task threshold (maximum task load)
- Umbrella tasks (series of uninterruptable tasks)

Task and mission analysis and functional analysis are relied on heavily for application of FAM early in system development. Major assumptions are required (particularly

concerning equipment reliability) for very early FAM implementation; however, as system development continues, these assumptions become fewer and more valid.

Two procedures of FAM are the Mission Evaluator and the Procedure Generator. The Mission Evaluator aspect of FAM computes mission reliabilities of allocation schemes, a gross workload measurement of each crewmember and man/machine task reliabilities. Principal uses of these aspect data are to select/modify various allocation schemes and to assist in identifying areas where specific allocation modifications are required.

The Procedures Generator derives data for the development of operational sequence diagrams and provides procedure statistics for allocation schemes.

The Mission Evaluator procedure is as follows:

1. Compute individual operator and machine reliabilities
2. Compute subsystem reliability (as a function of both human operator and equipment reliabilities)
3. Compound task reliabilities to determine mission success probabilities (for each allocation candidate)
4. Compute mission objectives success

The human reliability computation of step 1, above, is a reliability vs. task execution time function, i.e., the human reliability for a given task cannot be determined until a task execution time is determined. Simply stated, task execution time is a function of: (1) nominal execution time for that task; (2) perceived task load (sum of nominal task execution times for remaining operator tasks in the scenario); and (3) elapsed mission time. Task execution times are altered by a conversion factor in accordance with nominal task time requirements (to complete all tasks in a mission) and time remaining to complete those tasks. Task execution time, once determined, are inputted to find values of operator reliability for each task. Machine reliabilities are used as input by the user.

Procedure Generator operation is as follows:

1. Sort tasks according to
    - Must tasks (high priority)
    - Umbrella tasks (sequences)
    - Regular tasks
2. First task to execute is determined by:
    - Results of step 1, above
    - Earliest start time

- Task dependencies

3. Clock advances

4. Subsequent tasks are selected according to:

   - Earliest start time
   - Latest start time
   - Priorities, umbrella tasks

5. Tasks are selected and executed until either all tasks have been completed, or a task cannot be completed in available time.

FAM, in the course of task execution, collects and stores data such as: task start times, task scheduling, task interruptions, task time percentages (of total time) and simultaneous task performances, for output.

Specific outputs of . AM (Mission Evaluator and Procedures Generator) are as follows:

- Reliability of mission (total mission)
- Reliability of mission objectives
- Crewmembers workload estimation
- Task reliability (redundant man and machine reliabilities)
- Percent of tasks completed and interrupted
- Percent of mission time that tasks were being performed simultaneously

Task Analysis

Task analysis refers to methods used to specify inputs, behavioral steps, decisions and actions required of an operator to effectively perform the functions which have been allocated to him. Task analysis indicates what a person actually 'does' rather than what he is 'responsible' for. Meister and Rabideau (1965) have described task analysis as ". . .a model of system performance in terms of behavioral elements (perception, decision making, manipulation, etc.) in relation to some system output".

Although emphasis and techniques may vary between human engineers, the general philosophy for applying task analysis is relatively consistent. By obtaining an accurate description of operator tasks, the human factors specialist can begin to evaluate the proposed system in terms of the appropriate human factors criteria. As Kidd and Van Cott (1963) observe, "The objective or purpose of task analysis is to provide the basic 'building blocks' for the rest of the human engineering analysis".

In system development, the basic process of task analysis is one of inferring, from the actual or proposed design of the equipment, what tasks and sequences of tasks will be required of the operator when the system is completed. In addition to the actual equipment to be employed, the human engineer must be cognizant of such factors as safety and maintenance requirements which will impact operator performance. In conducting the analysis, the human factors specialist must first collect and organize all available information regarding the system especially for those functions allocated to human performance. Generally, this is accomplished through the use of a predesigned task analysis form, such as those depicted in Figures 9 to 15. Figure 9 presents the format used by ESSEX Corporation and displays the types of information that were gathered in the analysis of an actual system.

In developing a task analysis, the following types of information are collected and recorded in the appropriate row or column on the data form.

- STATION - records the name of the station or operator position at which the task is to be accomplished.
- DUTY - identifies the system process of which the task is a component.
- TASK - identifies the specific task which is to be accomplished. Entries into this column are ordered sequentially to assist the analyst in developing time lines, operational sequence diagrams, etc.
- ACTIVITY - describes what the operator must do to complete the task. The description should contain an action verb which adequately describes the operator's response (e.g., monitors, actuates, signals, etc.).
- EST. TIME (MIN.) - presents the amount of time estimated for the operator to complete the necessary activity. These data are useful in evaluating the ability of the system to operate within established time constraints.
- FREQUENCY - of the activity.
- INFORMATION/COMMUNICATION REQUIREMENTS - Under this heading, the human engineer describes the type of information the operator needs to perform the task, or the communication requirements of the task. The stimulus may be an out-of-tolerance display indication, an indication that maintenance is required, a signal from another operator, or some similar input that indicates the need to respond.
- CONTROL - In this column, the analyst enters the name or description of the control used for the activity.
- DISPLAY - In this column, the analyst describes the display used by the operator to perform the activity.
- INDICATION - Under this heading, the human engineer describes the type or source of feedback available to the operator which indicates that the necessary system response has occurred.

DUTY ______

STATION ______

ACTIVITY	ESTIMATED TIME TO PERFORM (MIN. OR SEC.)	FREQUENCY OF PERFORMANCE	INFORMATION/ COMMUNICATION REQUIREMENTS	ASSOCIATED CONTROLS	ASSOCIATED DISPLAYS	INDICATION	SKILL/ KNOWLEDGE REQUIREMENTS	POTENTIAL ERRORS	ERROR IMPACT

FIGURE 9
ESSEX CORPORATION STANDARD TASK ANALYSIS FORMAT

POSITION TITLE ____________________

DUTY	TASK	TIME	CONTROL	ACTIVITY	INDICATION

Duty — General activity in mission-oriented language
Task — Task name and code number
Time — Time to perform the task (including transitory and ready time)

Control — Control used to effect the task
Activity — Perceptual, decision or motor
Indication — Feedback information

SUBSYSTEM OPERATION INVOLVED	DUTIES AND TASKS	SPECIAL TOOLS AND GSE	SKILL IDENTIFICATION			TIME FREQ.
			NEWNESS	TYPE SKILL LEVEL OF DEMAND	CRITICALITY	

FIGURE 10
TASK ANALYSIS FOR DEVELOPING POSITION DESCRIPTIONS

TASK STEP	DISPLAY DESCRIPTION	DISPLAY CRITICAL VALUE	MEDIATION	CONTROL DESCRIPTION	CONTROL ACTION	INDICATION OF RESPONSE ADEQUACY
Job: Replace tire and wheel with spare						
Task 1.1: Secure wheels of car						
9	Car	On incline	Decision to select block for wheel. (Concepts 6, 12, 19)	Blocks	Approach	Blocks within easy reach
10	Blocks	Different sizes and shapes	Selection of one block. (Concepts 12, 19)	Block	Pick-up	Block in hand
12	Block	In hand	Decision to place under wheel. (Concepts 12, 19)	Block	Place under wheel	Block properly placed
12.5	Block	Under wheel	Decision to test adequacy of block. (Concepts 12, 19)	Emergency brake	Release	Car does not roll down hill

FIGURE 11
TASK ANALYSIS OF PROCEDURES

GROSS TASK ANALYSIS

TASK	DISPLAY: DESCRIPTION	DISPLAY: CRITICAL VALUES	DECISIONS	SUBTASKS LISTED	CHARACTERISTIC ERRORS OR MALFUNCTIONS
A. Set up before first run	Position of brake	Not in 9 o'clock position	Release brake - move to 9 o'clock position	1	
	Recall of last inking	Copy light since last inking (est.)	Measure ink - add if necessary	18, 19, 20, 21, 22	

ANALYSIS OF SUBTASKS

SUBTASK OR TASK	DISPLAY - CONTROL DESCRIPTIONS	CONTROL ACTION	INDICATION OF RESPONSE ADEQUACY	OBJECTIVE CRITERION OF RESPONSE ADEQUACY	CHARACTERISTIC ERRORS OR MALFUNCTIONS
A. Release brake	Brake	Turn clockwise (up)	Brake stop in 9 o'clock position		
B. Attach the stencil	Wheel	Turn	Stencil head clamp available		
	Stencil head clamp	Lift left end	Stencil head clamp loosens		

FIGURE 12
TWO-LEVEL TASK ANALYSIS

FUNCTION:	(1)	Operate aircraft power plant and system controls
TASK:	(2)	Control jet engine operation

SUBTASKS (3)	ACTION STIMULUS (4)	REQUIRED ACTION (5)	FEEDBACK (6)	TASK CLASSIFICATION (7)	POTENTIAL ERRORS (8)	TIME (9) ALLOWABLE (9a)	TIME (9) NECESSARY (9b)	WORK STATION (10)	SKILL LEVEL (11)
3.1 Adjust engine r.p.m.	4.1 Engine r.p.m. on tachometer	5.1 Depress throttle control downward	6.1 Increase in indicated tachometer r.p.m.	7.1 Operator task, aircraft commander	8.1.a Misread tachometer 8.1.b Fail to adjust throttle to proper r.p.m.	9a.1 10 sec.	9b.1 2 sec.	10.1 Aircraft commander's seat	11.1 Low

FIGURE 13
REPRESENTATIVE TASK ANALYSIS

FIGURE 14
BEHAVIORAL ANALYSIS OF TASKS WORKSHEET

TEXT		GRAPHICS	
RESPONSE	CUE	CONTEXT	FOCUS
Access			
1. Pull hood latch to left and hold	Hood latch	View of vehicle front	Hood latch
2. Lift hood, then release latch	Hood	View of hood raised, support bar straight	Hood
3. Pull support bar to front	Support bar	View showing support bar in final position	Support bar
Remove Air Cleaner Base			
1. Using blade screw driver loosen lower clamp screw	Clamp screw	View of right side of engine	Inset of clamp screw
2. Loosen clamp	Clamp	View showing clamp loose	Clamp
3. Slide off air cleaner hose	Air cleaner hose	View showing hose removed	Air cleaner hose
Remove Vacuum Line			
1. Using ____ wrench unscrew vacuum line nut	Vacuum line nut	View of right side of engine	Inset of nut
2. Pull out vacuum line	Vacuum line	View showing vacuum line disconnected	Vacuum line
Remove Throttle Linkage			
1. Using ____ wrench unscrew nut	Throttle link nut	View of right side of engine	Inset of nut
2. Pull linkage out	Linkage	View showing linkage disconnected	Linkage

Found in Troubleshooting	Code						System Hardware Item	Reference Designator	Maintenance Function 1 Adjust	2 Align	3 Calibrate	4 Checkout/Troubleshoot	5 Clean	6 Disassemble/Assemble	7 Inspect	8 Lubricate	9 Operate	10 Remove/Install	11 Repair	12 Service	13	Notes

FIGURE 15
MAINTENANCE TASK ANALYSIS

- SKILLS/KNOWLEDGE - The analyst uses this column to describe skills and/or knowledge required by the operator to complete the task.
- POTENTIAL ERRORS/CONSTRAINTS - In this column, the analyst lists probable sources of error based on the type of response required of the operator and characteristics of the equipment used.
- ERROR IMPACT - Under this heading, the human factors specialist describes the effect the various possible errors will have on mission effectiveness.

The quality of information available to the human engineer and the purpose of the analysis will determine the detail to which the analyst describes the various components of the task.

The data gathered in the course of a task analysis have valuable applications throughout the human factors design process. Examples of these applications are presented below.

- Manning Requirements - By examining the types of tasks to be accomplished and the skill-knowledge requirements of the operator, the human engineer may determine the number and types of personnel needed to accomplish the mission.
- Training - Task analysis provides the human factors specialist with the information necessary to specify the level of competency required of an operator to effectively perform at the designated workstation.
- Workstation Design - The control and display information provided by the task analysis will assist the human engineer in describing the types of equipment necessary for the workstation. The sequential ordering of the tasks and the frequency of the activities will aid the analyst in determining the optimal configuration of the equipment at the station.
- Communication Requirements - Data generated by the task analysis will help the analyst determine the communication links (source and content) which will be required by the station operator.
- Maintenance Requirements - The value of task analysis to maintenance requirements is two-fold. First, the analysis provides information regarding the precision required of the equipment. Second, a separate task analysis can be performed to describe the maintenance process itself.
- Job Performance Aids - To develop effective job performance aids, the human engineer requires detailed descriptions of what tasks the operator must perform and what skills and information are required to perform them. A well developed task analysis may be used as a step-by-step introduction to the system, or as a source for operational and training manuals.
- Test and Evaluation - The descriptions of operator performance inherent in task analysis can be used to generate performance criteria

with which to evaluate the effectiveness of a system and/or its operators.

The following are examples of task analysis methods, varying as to terminologies, formats, taxonomies and types of behavioral features and emphasis.

A method developed by Chenzoff and Folley (1965) places tasks in behavioral classes to be used in training design decisions. The activities (components) are coded according to their main tasks. The columns list the following:

- Number of task code (activity)
- Person performing the activity
- Type of activity
  - procedural
  - monitoring
  - perceptual motor
  - communication
  - decision making
- Sequence of the activity
  - fixed (F)
  - variable (V)
- Ratings
  - 0-not essential
    1-necessary but not demanding
    2-critical
- Coordination
  - number of persons needed to perform the task (alone or a team)
    1=1 man
    2=2 men
    3=3 or more
- Specialized Behavior - Amount of training required to progress from entry-level behavior to exit-level behavior
  0=not related to previous experience
  1=readily learned
- Difficulty
- Dynamic Condition
- Remarks

Review of the data gathered can thus enable the analyst to set up the functional requirements of the training system.

Miller's (1963) format is that of a matrix with tasks assigned along one coordinate representing requirements for different aspects of training and along a second coordinate listing the different phases of work. The cells within the matrix are coded to indicate the task and training equipment needed for the training aids. These codes are formed from

separate activity descriptions (i.e., time demands, perceptual difficulties, feedback, etc.). Miller also characterizes the different trainers available as to "principal feature, critical factor, training value and limitations" and human engineering aspects.

The steps are:

1. Listing of tasks at a broad level
2. Grouping tasks as to time or kind or both
3. Reviewing activities in each task in light of task groups
4. Coding as to use in different stages of training

In addition, there is a task-time chart, a list of conditions under which work is performed and a catalogue of activities performed in the task (perceptual difficulties, decision making, time demands, equipment malfunction and correction, attention, short-term recall, long-term knowledge for contingencies, correctness of response feedback and displays, and controls).

Miller's instructions for performing the task analysis are:

1. Prepare statement of requirements
    a. list types of missions (if tasks vary from one mission to another)
    b. list tasks
    c. prepare block diagram of tasks as they occur in the work cycle
    d. describe the conditions under which the tasks are performed (including the "signs whereby the operator recognizes the need for performing the task")
    e. describe the activities in the task (including information regarding time demands, etc.)
2. Prepare table of tasks to be taught and types of trainers

The basic element of this type of task analysis is the "classification of training devices on a kind of habit or skill provided the trainee, rather than the subject matter taught".

De Maree's (1961) form of task analysis utilizes a descriptive list of tasks presented in tabular form and is based on "a list of behavior with several broad stages of training creating groups of tasks called 'training functions'". Each of these functions is categorized according to ten "Training Equipment Effectiveness Characteristics". The object is to scale each of these ten in order to define the tasks as to their specifics and as to trainees and context effectiveness characteristics.

Steps taken on Training Equipment Requirements Data Sheet are:

1. Task identification (from "Quantitative and Qualitative Personnel Requirements Information Report")
2. Differentiation of training functions:

a. knowledge
b. skills and task components
c. whole task performance
d. integrated task performances
e. familiarization trainers
f. instructed-response trainers
g. automated skill trainers

3. Proficiency levels tabulated based on extent of supervision, etc.

4. Effectiveness characteristics coded by degree of complexity

5. Degree of utilization estimated

De Maree's method is similar to Miller's with the addition of means for eliciting information regarding training needs, level of proficiency and the trainee's inputs. It is, therefore, a more complete and explicit form of task analysis.

According to Sherrill (1976), the purpose of task analysis is the design of criterion tests, since good performance tests must be designed before training can be designed.

The size of the task, the boundaries of the task and the potential sources of variance are the key concepts used by Sherrill.

- Concept 1 - Size of task. A task can be a part of a larger task, and tasks should be set up on a continuum—from the smallest to the most complex.
- Concept 2 - Boundaries of tasks. This is basically the information gathered from a task analysis. The categories of information are:
  - the initiating cues
  - the terminating cues
  - the givens

  All three elements must be identified when performing a task analysis to decide what type of training criteria are needed.
- Concept 3 - Identification of potential sources of variance. During task analysis a systematic laying out of the task should bring out the possibilities of misses, incorrect performance or sources of variance. Different levels of specificity, from macro to micro, enable the analyst to back-track when he observes a problem not recorded before. A type of task analysis used would be the logic tree. Also used is an outline form which depicts a straightforward, stepwise analysis of a task—step one, two, three (see page 3). The branching form is frequently encountered in maintenance manuals. The variable format is used in tasks in personnel work—tasks which have many randomly occurring cues and many different outcomes from the different sets used.

In determining which of these forms to use, Sherrill suggests examining the task description. If compound or complex sentences are used and words such as "except", "unless", "but", and "when" appear, the variable form should be used to analyze the task.

All three concepts—outline, branching and variable—are used in identifying the outcome of the task (the criteria) before the inputs (learning materials) are developed.

As part of the development cycle for FPJPA (fully proceduralized JPAs) Shriver (1975) proposes BAT (Behavioral Analysis of Tasks) which "would surface most of the important environment cues that would be missed by a conventional 'hands on' analysis, cues that are necessary for highly effective FPJPA".

The basic BAT format involves "Cues" and "Responses". The analyst must highlight each individual cue which elicits a response from the individual. For example, if a maintenance man is to open an access panel, there is no overall cue for this response since all he sees is the panel. However, the next cue would be the screws holding the panel. His response to these cues would be to put up a screwdriver and turn. This goes into the Response column. The next step involves a CUE entry of turning a handle to open the panel. If the cue is anything but a simple action, an additional cue must be sought by the analyst and recorded.

Graphics are produced from the cues to produce a diagram which the maintenance man can compare with the real equipment, such as a picture of the inside of the panel after the cue of opening.

The BAT is constructed step-by-step and with full detail. It also includes error information, or what will happen if a step is performed incorrectly. Each step in the task analysis includes a verbal description and a diagram.

Shriver acknowledges that the construction of a BAT requires expensive, highly skilled and tedious work on the part of the analyst. He feels, however, that its use in the FPJPA development cycle will lead to a quality result on minimum cost.

Operational Sequence Analysis

Along with application of Task Analysis, development of the Operational Sequence Diagram (OSD) can begin. The OSD (Figures 16 and 17) is a graphic representation of the operation of a system which shows: operational links, communications networks and links, the phasing and syncronizing of events, functional allocations, man/machine interactions, decision points and operational task dependencies. The technique is highly valuable to the HF engineer. The OSD can be used to:

- Develop operational procedures
- Evaluate man/machine interfaces
- Evaluate functional allocations
- Identify critical mission areas
- Identify task over- and underload areas for given operators during given mission phases

FIGURE 16
REPRESENTATIVE OSD

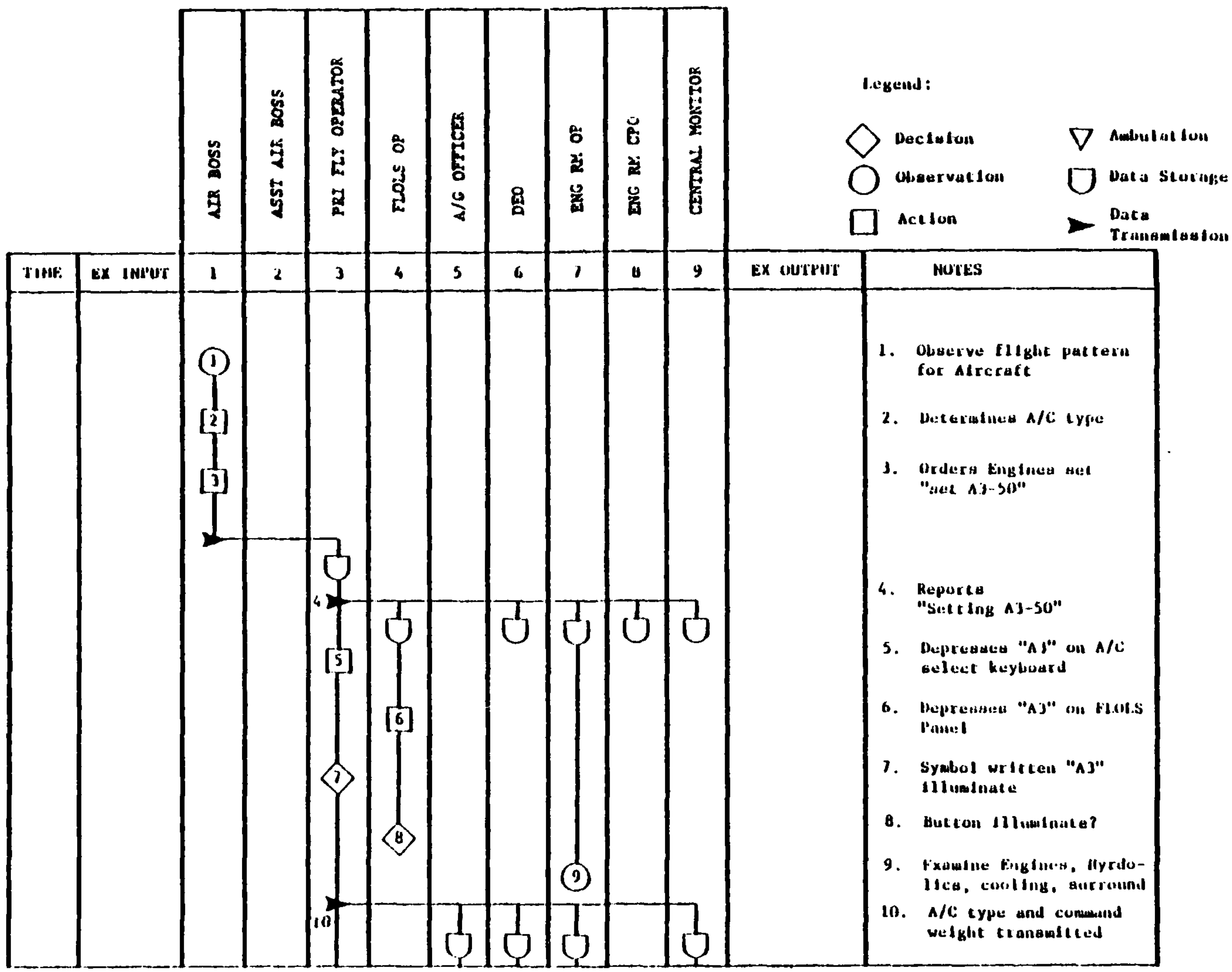


FIGURE 16
(Continued)

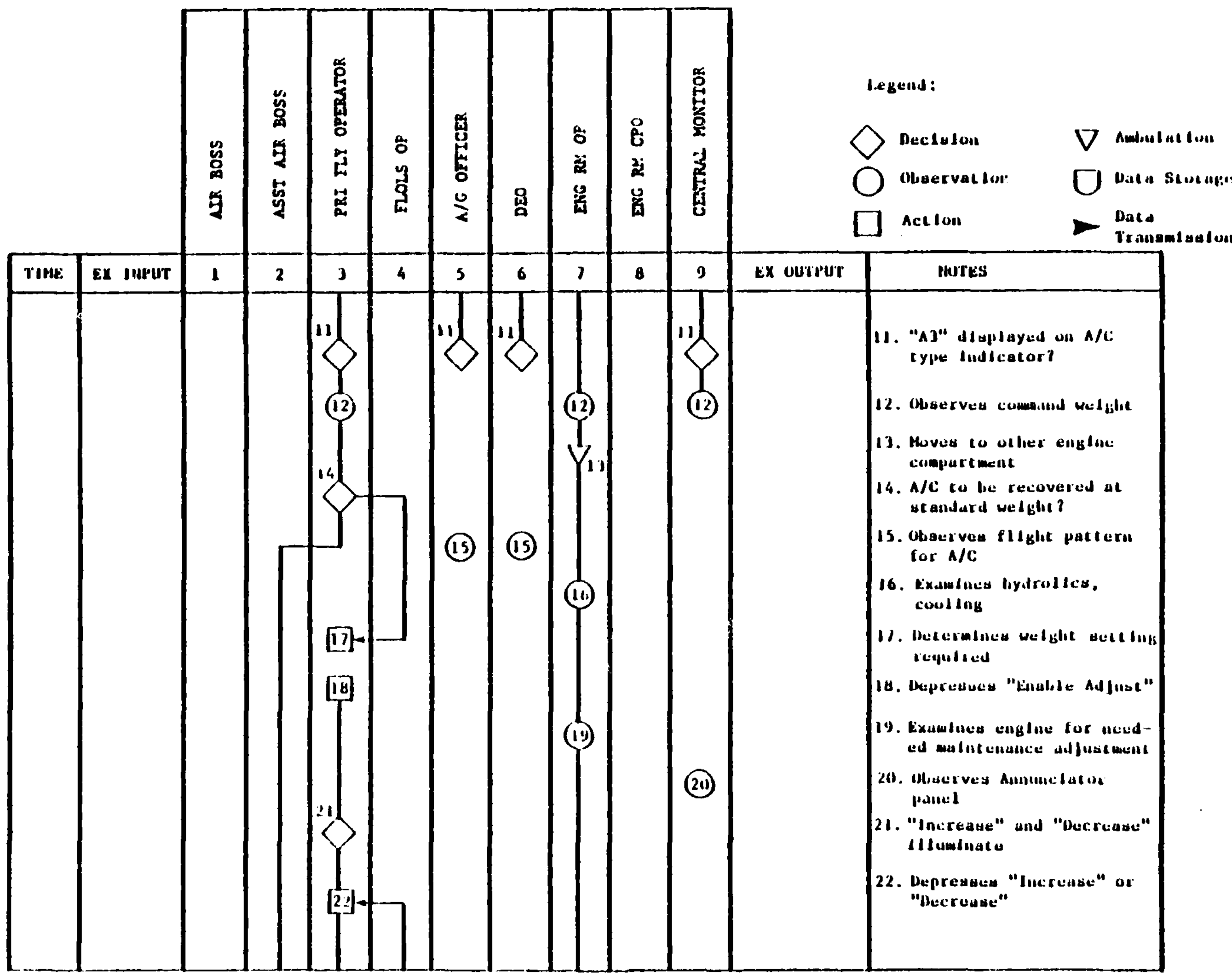
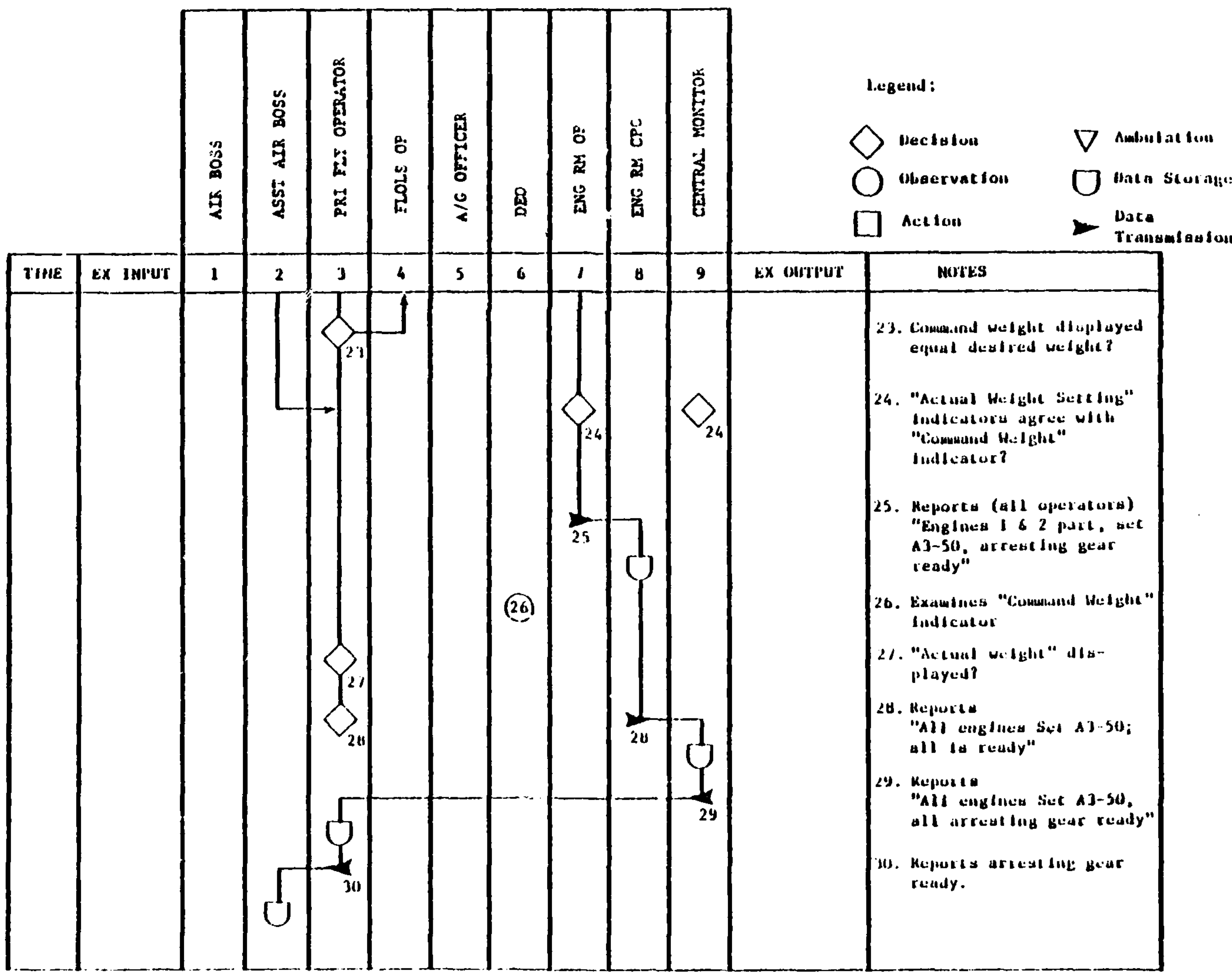
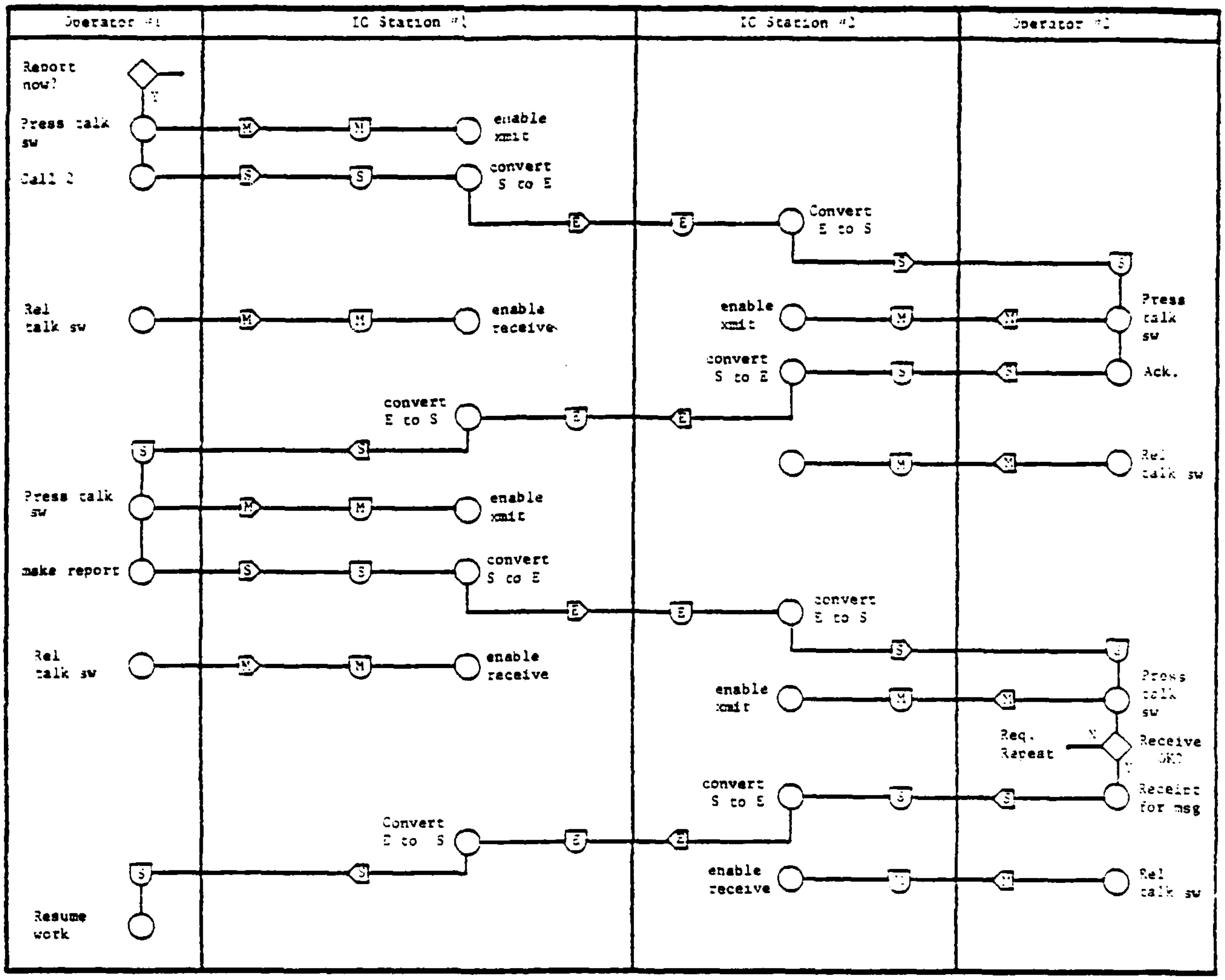


FIGURE 16
(Continued)





Notes on Operational Sequence Diagram

Symbols

- Decision
- Operation
- Transmission
- Receipt
- Delay
- Inspect, Monitor
- Store

Links

M	mechanical or manual
E	electrical
V	visual
S	sound
etc.	

Stations or subsystems are shown by columns
Sequential time progresses down the page

FIGURE 17
REPRESENTATIVE OSD

- Identify critical decision/action points
- Develop workspace design and evaluation criteria
- Identify areas of high error likelihood

In short, the OSD should (at various times in the systems development) provide information sufficient to aid in the design, evaluation and documentation of the system. The reason that the technique is so valuable lies in the fact that in order to establish a good OSD, a great deal of information must be gathered and analyzed before the diagram can be developed. Data to develop the OSD are gathered from Functional Analysis (specifically the Functional Block Diagram), Task Analysis (for task sequencing, identification of task type, duration, etc.), Functional Allocations, analysis of similar systems and requirements analysis.

The OSD is typically an iterative technique, beginning with a description of more or less theoretical system. As development of the system and implementation of HF techniques continues (subsystems identification of functional reallocations, workstation designs, equipment designs, so on) the data are incorporated into the OSD such that it is maintained to reflect current system configuration. Use of the OSD itself (as an evaluation tool) will suggest design and operational changes, calling for an updated version of the tool.

The fact that the OSD requires a good deal of input information and is made to be current with progressively greater system detail makes it an expensive and time consuming technique. The Automated-OSD (A-OSD) has been developed to help alleviate these problems (Lahey, 1970, Larson and Willis, 1970). The aid (which emphasizes the usefulness of OSD as a timeline), uses a character printer to make OSDs. Lines are represented by strings of dots (periods) and rather than the use of symbols, characters of the alphabet are used to indicate types of actions:

- Decision
- Inspection
- Operation
- Recall/retrieve (information)
- Store
- Transmit

and mode of action:

- Bodily
- Cognitive

- Electrical
- Mechanical
- Auditory
- Tactile
- Visual

Descriptions of each entry in the "diagram" are printed to the right of the action (e.g., "monitors screen").

Changes and additions to the OSD are entered mechanically and a new OSD is then printed. The developers state that lines can easily be drawn manually and that the use of characters as descriptors are easily learned.

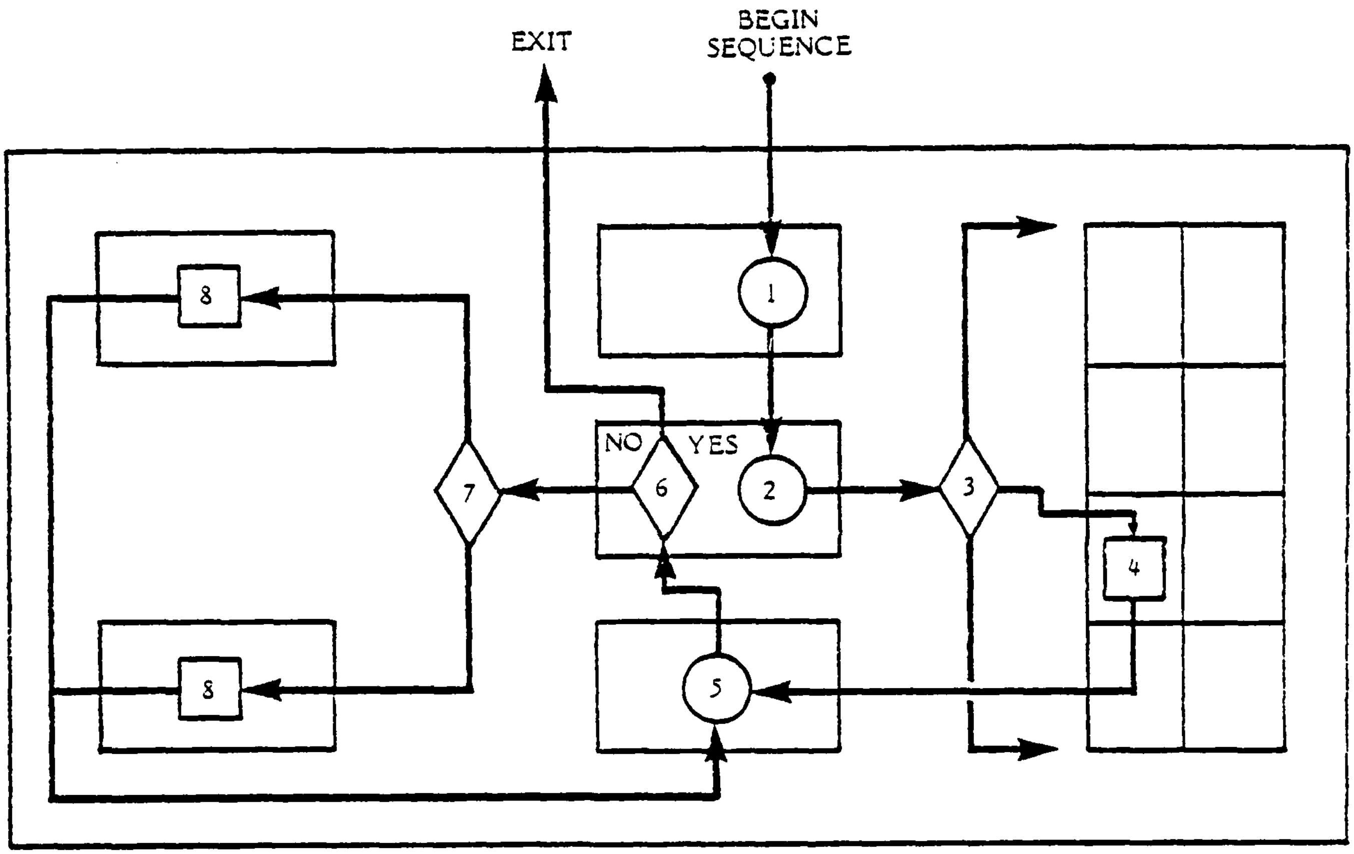
It seems evident that an interactive program for the development of an OSD would be of great benefit for the updating of the diagrams, particularly with larger, more complex OSDs.

Other types of Operation Sequence Diagrams are the Spacial OSD (S-OSD) and the Task Analysis - OSD (TA/OSD). The first type, the S-OSD (see example in Figure 18), is very much like a link analysis. It represents a panel concept, which incorporates the sequences of events of an operator as he interacts with the panel.

The TA/OSD is a marriage of Task Analysis and Operational Sequence Diagramming. An example of TA/OSD is presented in Figure 19. The technique, as can be seen by the figure, provides more detailed task descriptions than previously described OSDs. This technique, although more complex and less suited (perhaps) for computerization (using a graphics terminal), provides more information that is readily available to the HF analyst than task analysis or OSDs alone.

In preparing the TA/OSD, the minimum data requirements are task sequences, functional allocations and task requirements data. The diagram and task analysis may proceed in parallel, i.e., analyze tasks, incorporate into OSD, analyze OSD, input to task analysis.

A useful tool for assisting Task Analysis and OSD development is the Decision-Action Diagram. The purposes of the tool are to identify, analyze and graphically represent decision points in terms of: (1) decisions to be made; (2) options; (3) rates; and (4) subsequent actions taken as a result of specific decisions. Analysis of the diagram will reveal common actions performed at different decision points, common decisions and series of unique decision sets, and decision set outputs. The analysis can also help to identify critical decision points, required information and potential effects of erroneous decisions.



1. Observe System Requirement
2. Observe Input Data Requirement
3. Determine Input Channel
4. Make Input
5. Observe Feedback Indication
6. Agree with Required Input?
7. Select Adjustment Mode
8. Perform Adjustment

FIGURE 18
SPACIAL OSD

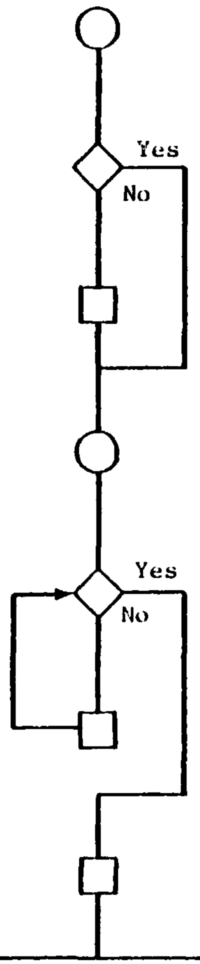
SUBFUNCTION	OSD	ACTION	FEEDBACK	TIME MIN/SEC	SKILL KNOWLEDGE REQUIREMENTS	POTENTIAL PROBLEMS/REMARKS
System Checkout		Observe Status		0:00		
		System Enabled?		0:05	Knowledge of Indication	
		Enable	Display			
		Observe Pressure Indications		0:10		
		In Tolerance Range		0:15	Tolerance Range	Critical to Mission
		Adjust PSI	Gauge		Adjust Procedures	
		Set Values				Value Selection

FIGURE 19
TASK ANALYSIS OSD

The method of diagram development is tedious but relatively straightforward. Requirements analysis is reviewed to assist in identifying decision points and options. At each decision point and for each decision option, subsequent activities and/or decisions are diagrammed, and subsequent decisions and actions are likewise diagrammed for each potential output of previous decisions or actions.

An example of a Decision-Action Diagram for a relatively simple operation is shown in Figure 20.

3.2 Technologies Applicable During Validation Phase

The major efforts of the HF engineer during this phase are to develop concepts towards:

- Workspace design (including controls, displays, consoles, panels, environment, communications and so forth)
- Maintenance designs
- Training systems designs

and to evaluate these concepts by application of evaluative technologies and formal HFE Test and Evaluation.

Of the technologies surveyed which are applicable to this phase most fall into two categories: diagnostic design and/or diagnostic/evaluative (typically for design trade-offs). Technologies for design are scarce; typically, design concepts are formulated from:

- The HFE data bank for the system (OSDs, task analyses, etc.)
- Identification of design constraints and requirements (cost, convention)
- Application of human factor design principals
- Design standards (MIL STD 1472B, for example)

The basic procedure for the HF engineer during this phase are:

1. Requirements/constraints identification
2. Evaluation and trade-offs
3. Design modifications and trade-offs
4. Iterations of steps above as required

Control/Display Selection

HFE Principles and Criteria can aid in the selection and/or design of controls and displays. The Human Engineering Guide to Equipment Design (Van Cott and Kinkade,

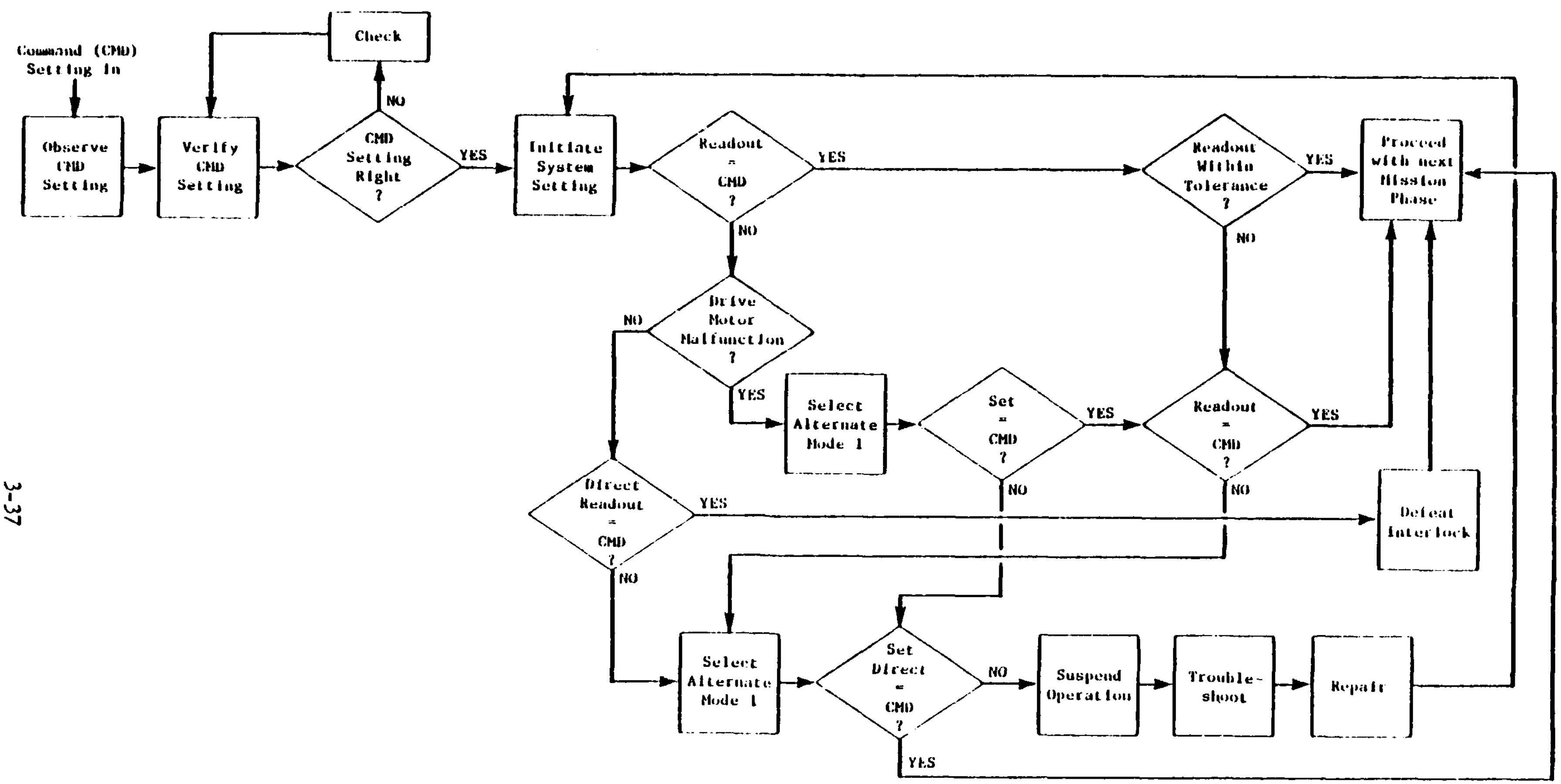


FIGURE 20
DECISION ACTION DIAGRAM
(from Baker and Malone, 1978)

1972) provides general guidelines in terms of control and display selection. Specific information requirements for control selection are: function, task requirements (precision, speed), information requirements, workspace requirements (layouts, workspace availability), and consequences of control error.

General principles are also provided, e.g.:

- Controls should not overburden any particular limb
- Continuous controls should be used for requirements where continuous settings exist
- Discrete controls should be selected for discrete system settings
- Functionally related controls should be combined

Criteria for Controls and Displays are available in MIL-STD-1472, NATO Agreements, etc. MIL-STD-1472 provides criteria regarding:

- Integration
- Sizes/shape
- Colors
- Labelling
- Reach distances
- Number of discrete positions, etc.

for various types of Controls and Displays (cranks, CRTs, legend lights, etc.).

AIR Data Store

The American Institute for Research Data Store (AIR Data Store) (Meister, 1971) was developed to aid in the selection of controls and displays for workspaces via predictions of performance time and reliability of performance. The AIR Data Store is in part a compilation of control and display types and predicted execution times and reliabilities for each.

The procedure for application of the data store is as follows. For each required control and display, a type is selected (pushbutton, toggle switch, guage, so on) and the data store is referenced for predicted mean execution time and probability of success in terms of operation. Execution times are added, yielding total time (for operation) and the probabilities compounded. The goal is to minimize total time and maximize reliability via control/display type selection.

While the AIR Data Store does not contend with such issues as decision reliability (e.g., an operator's selection of the appropriate control), it may be valuable as a trade-off tool or an equipment selection tool.

Link Analysis

Link analysis is a method which aids in the development of man and machine arrangements. The purpose of link analysis is to aid in minimizing, for any system or workspace, considerations such as traffic flow, observational distances, and information flow distances.

Data requirements for the analysis are as follows:

- Information flow requirements
- Information flow medium (auditory, visual, ambulatory, electronic)
- Station requirements (number of stations, number of operators, functional allocations)
- Special allocation constraints

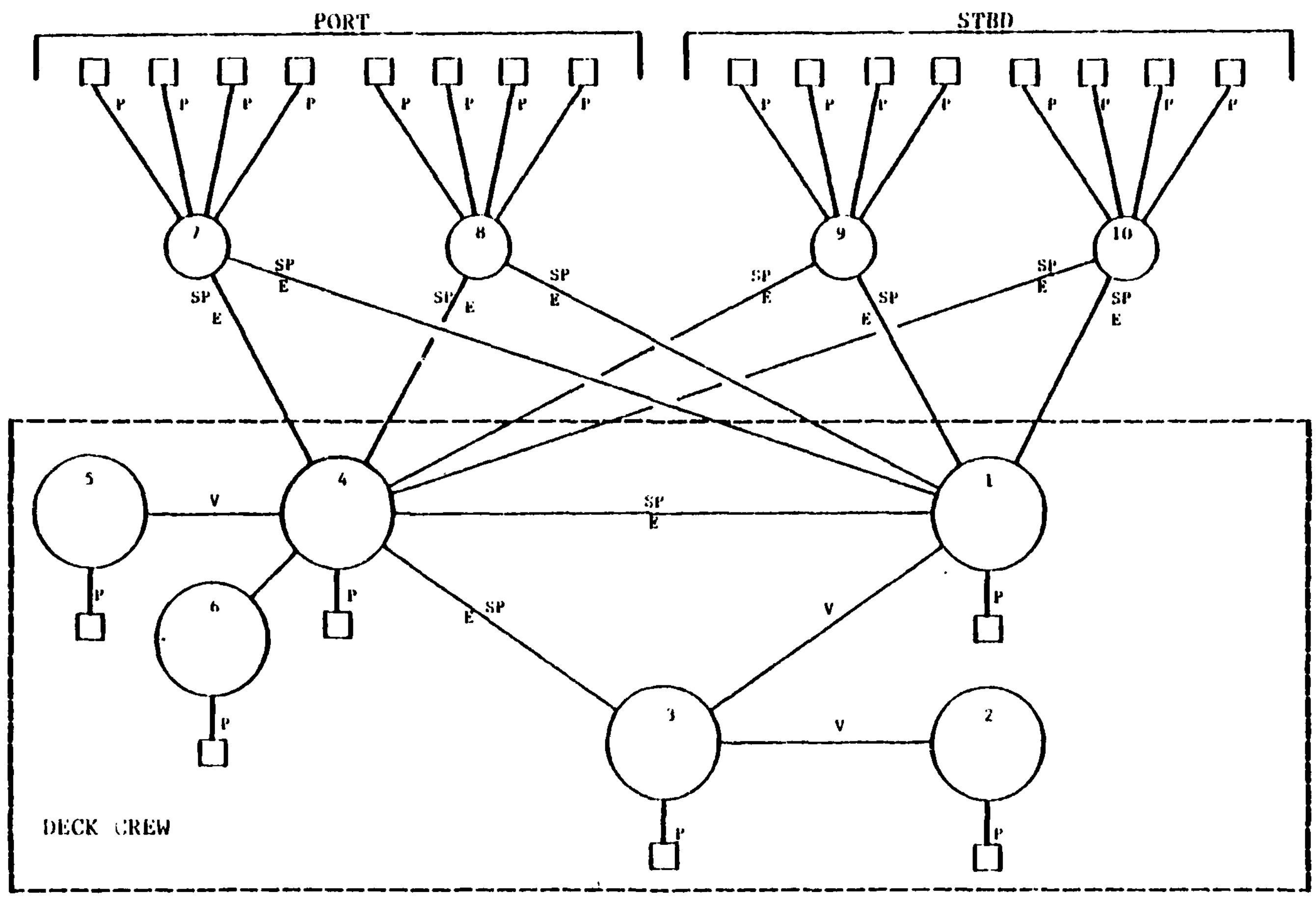
According to Thompson (1972), link analysis is applied in nine discrete steps, as follows:

- Identify (by a circle, on a piece of paper) each required operation
- Identify (by a square) equipment requirements
- Identify links (lines) between appropriate men
- Identify links between men and machines
- Simplify the arrangement by reducing the number of crossing links
- Evaluate each link for importance and frequency of use
- Redraw the diagram reducing link length and number of crossing links in accordance with step 6
- Fit the diagram into the available work area (by redrawing if necessary), or design work area around link diagram
- Confirm the link diagram by drawing to scale equipment and machines.

The link analysis (Figure 21) can be applied at a variety of levels, e.g., a CIC workspace, or at a total systems level, such as a ship or aircraft.

Correlation Matrix

A tool to expand the power and utility of the link analysis is the Correlation Matrix (Geer, 1976), which shows the number and criticality of information transfers within each link. This tool is simply a listing of operator (or station) positions adjacent to half of an N by N matrix (example, Figure 22), where N is the number of operators or stations. Within each cell of the matrix are the number and criticality of specific link types (e.g., observations, ambulatory, auditory, etc.).



LEGEND:

○ – OPERATOR

□ – EQUIPMENT

P – PANEL INTERFACE

SP – SOUND POWERED PHONE

V – VISUAL

E – ELECTRONIC

FIGURE 21
LINK ANALYSIS

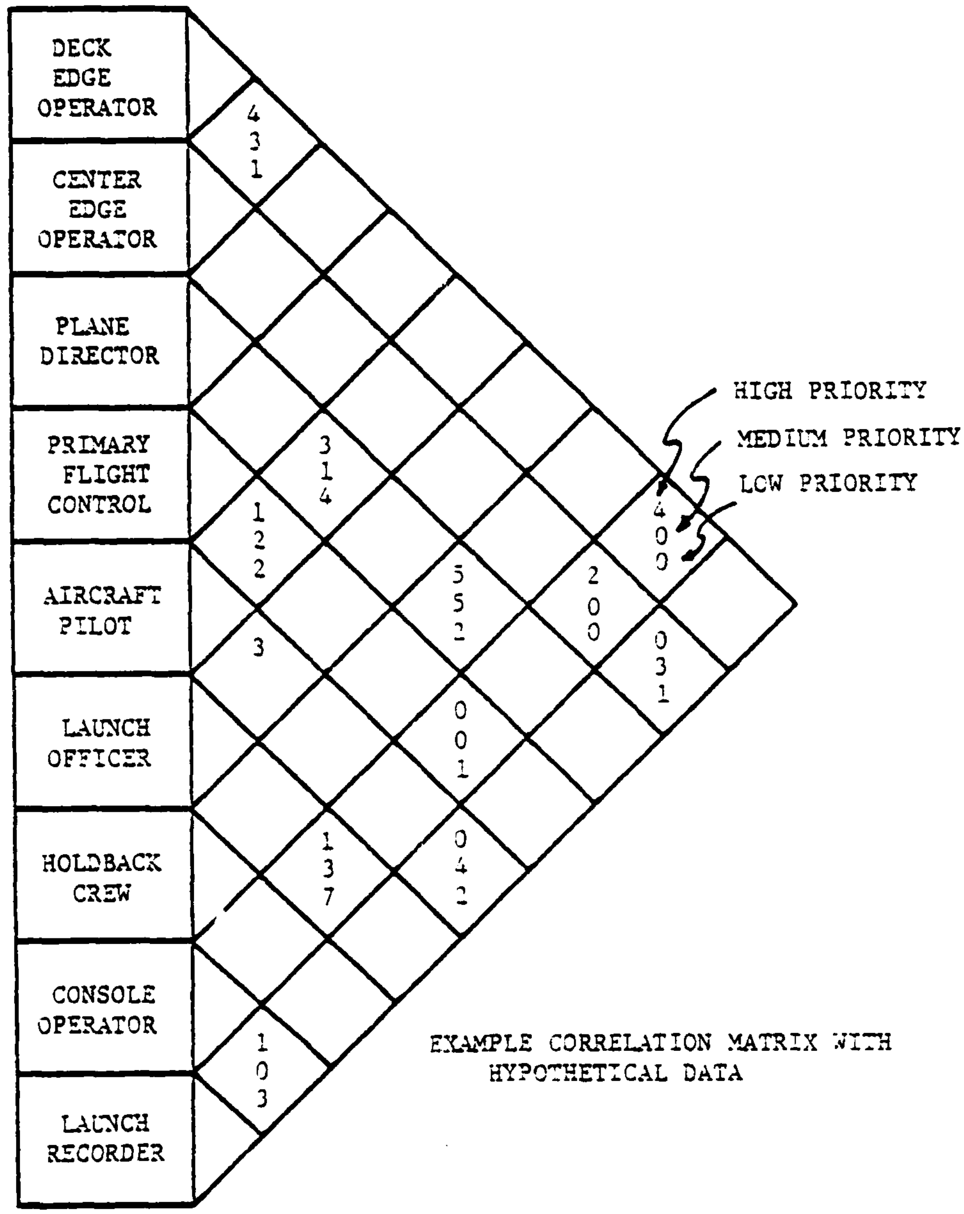


FIGURE 22
CORRELATION MATRIX

HFE Principles for Console Design

Control and Display panel/console concepts are typically generated from a variety of system data; operational sequences, system/mission requirements, task requirements, control and display type selection, etc., and HFE design principles such as:

- Centrality - critical panel components are placed centrally in an operator's visual and operational sphere
- Sequence of Operations - components are placed according to sequence of functional use and/or reference, minimizing visual and motor transition times and distances
- Criticality/Importance - critical/important components are centrally located; less critical/important components are located more in the operational periphery
- Functional Grouping - functionally related controls and displays are functionally grouped
- Left to Right/Top to Bottom Usage - panel components should be used sequentially from left to right, or top to bottom
- Compatibility - controls, displays and whole panels should be compatible in terms of indexing, layout, coding, etc., in order to minimize decoding requirements

The object in developing console concepts is to maximize panel design in terms of these principles, e.g., a panel offering sequential usage of components, centrally located critical controls and displays, etc. Some source books on human engineering design principals and criteria are as follows:

- Human Fac[illegible] Engineering Design for Army Material, MIL-HDBK-759, 19[illegible]
- Naval Ship Systems Command Display Illumination Design Guide, Section II; Human Factors, NELC, 1973
- Guide to Human Engineering Design for Visual Displays, Bunker-Ramo Corporation, 1969
- Data Book for Human Factors Engineers, Vol. I Human Engineering Data, Man Factors Inc., 1969
- Data Book for Human Factors Engineers, Vol. II, Common Formulas, Metrics, Definitions, Man Factors, 1969
- Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472, 1974
- Air Force Systems Command Design Handbook 1-3 Human Factors Engineering, AFSC, 1977
- Human Performance Tradeoff Curves for Use in the Design of Navy Systems, APS, 1978
- Human Engineering Guide to Equipment Design, Joint Army-Navy-Air Force Steering Committee, 1972
- Bioastronautics Data Book, NASA, 1973

Some tools to assist in the generation of workspace and panel concepts are:

- CRAFT (Computerized Relative Allocation of Facilities)
- WOLAP (Workspace Optimization and Layout Planning)
- Linear Programming
- CAFES CAD (CAFES Computer Aided Design)

CRAFT

CRAFT (Coburn and Lowe, 1976) is a computer program which may be implemented to identify optimum control and display layouts on a panel, based on:

- Movement requirements
- Frequency of control and display use
- Control and display distance (grouping of associated controls and displays). (The technique does not, however, incorporate control/display criticality in the program.)
- An initial panel layout (and associated data such as initial distances, control/display relationships)
- Frequency of use for each control and display
- Eye and hand motion rate data
- Eye and hand workload data

The program makes layout changes and computes cost factors (essentially trade-offs, e.g., extent of hand movement requirements vs. visual workload). An output of cost (or a figure of merit) figures results from the computation of cost for all combinations of panel layout (all possible control display exchanges). The technique can be applied at the level of controls and displays, groups of controls and display, subpanels and panels. Therefore, after having computed minimum cost for groups of controls and displays (i.e., for four different groups), these four may then be input to CRAFT to determine minimum cost of subpanels, etc.

WOLAP

A program similar to CRAFT is WOLAP (Rabideau and Luk, 1974). The technique, according to the authors, has two advantages over CRAFT: (1) the method "yields many quantitatively optimized solutions", and (2) "functional links and sequential links are given proper consideration in the design".

The method of WOLAP operation is as follows:

1. An initial panel layout is evaluated by the program and a cost figure computed.
2. Panel components are randomly rearranged.

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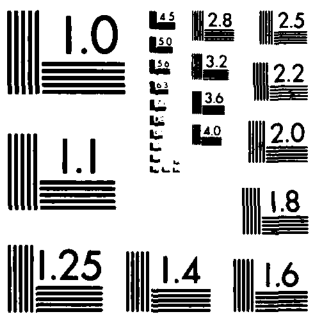


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

3. Cost is computed for the arrangement.
4. Steps 2 and 3 are performed a prescribed number of times (by the user).
5. The program retrieves the three layouts with the lowest cost and the initial layout.
6. Layouts and cost are printed for four configurations.

Figure 23 shows the general flow of the WOLAP Program.

In WOLAP, cost is figured as a function of:

- Transition distances (visual, manual)
- Weighting of components that are accessed
- Probability of transitions

for all possible transitions. Required inputs are as follows:

- Relative positions of panel components in an X-Y plane (initial layout)
- Frequency array data table (data on operational links of panel components and hands, eyes)
- Visual null (on the X-Y plane)
- Manual null (on the X-Y plane)
- Total number of instrument components
- Number of iterations required (number of randomly generated configurations)
- Relative weighting of controls

Like CRAFT, WOLAP can be implemented at the component, subpanel or panel level.

The above techniques are based in part on the manual Linear Programming technique reported by Freud and Sadosky (1967). The manual approach uses control/display spacing, visual transitions and frequency of use as input data. However, the algorithm reported was designed to determine panel configurations minimizing eye travel alone, the subsequent techniques would seem to have definite advantages due to this limitation.

CAD

The Computer-Aided Design (CAD) model of CAFES has been designed to assist in developing crew station configurations (specifically cockpit configurations) which are consistent with mission requirements, military standards and specifications, and cost and technical constraints and considerations.

WOLAP Process
(Adapted From Rapideau)

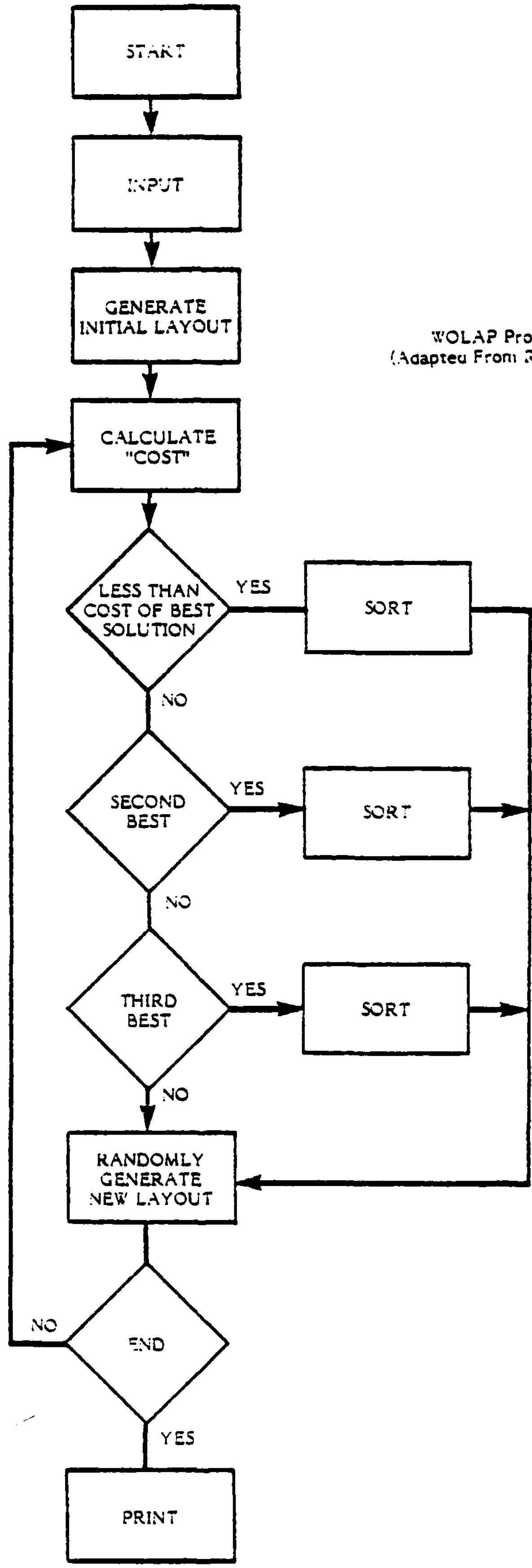


FIGURE 23
WOLAP PROCESS

CAD is defined as having three classes of functions: cockpit geometry development, cockpit design analysis and pictorial. Concept geometry development is essentially a means to define a workspace within the program, to tailor and scale the workspace dimensions, and to allocate workspace functional areas. Cockpit design can be analyzed to assist in determining the suitability of any design consideration. This group of CAD functions aids in assessing external and internal vision characteristics of a given cockpit design with a given eye reference point, analyzing and identifying potential reach problems in a workspace, and determining if emergency escape can be made from a workspace by various sized crewmembers, different seat positions, etc.

To use CAD, a variety of input data is required, e.g., a defined workspace, which can include instrument groups, control panels, controls (including reference point, shape, etc.), physical boundaries and so on. Also input are data concerning reach envelopes, scale factors (to modify sizes of workspaces), eye reference points, transparent surfaces, and opaque surfaces.

CAD can analyze these geometric data and output upon user request:

- A listing of items which penetrate the escape envelope of predefined sizes, also providing the penetrating component, its level of penetration and the item being penetrated
- Crew station Geometry Data
- External vision
- Derivations in reach distances between reach limits and cockpit locations for both hands and feet
- Vision distances from design eye reference point to points on a panel surface
- Vision plane intersection

Display Evaluation Index

A method for evaluating control and display effectiveness is the Display Evaluative Index (DEI) (Miehle and Siegel, 1965). The purpose of this technique is to compute a figure of merit regarding display utility; i.e., to provide an operator with information which can be processed such that subsequent control activations will aid in the performance of a task.

The technique is implemented by first identifying control, display and task characteristics. Factors are measured and a formula combines the data to yield a figure of merit. Inputs to the formula are as follows:

- Link weight (1 or 2, depending upon amount of information in an informative transfer (link), link weight is a figure of stress)

- Number of indicators
- Number of controls
- Number of used controls and displays in a task
- Total number of instructional and information links
- Total number of controls and displays
- Information in digits (associated with control, display or information transfer)
- Time for all task transfers
- Total time for a task to be completed
- Information mismatch (between control and associated display)
- Total number of critical links

"The formula is based on ten constructs and is designed so that for an 'ideal' system the resultant index value will be unity." To apply the technique requires the construction of a transfer chart, which is similar to the S-OSD and correlation matrix. The number and presence of control and display links may then be identified. The transfer chart itself may be constructed from OSDs, task analyses, equipment concepts and control, display and communications requirements analyses.

While the DEI does not predict human error (in terms of a probability), it does provide an index of operability for a panel or console configuration and, therefore, provides valuable trade-off information.

APS

The Analytic Profile System (APS) (Siegel, Fischl and Macpherson, 1975) is another technique to evaluate the adequacy of displays. The technique requires that the subjects make judgments concerning displays along the following dimensions (derived by multi-dimensional scaling):

- Stimulus numerosity
- Primary coding
- Contextual/discrimination
- Structure scanning
- Critical relationships
- Cue integration
- Cognitive Processing Activity

Judgments are made by reading statements relating to each factor ("At first glance seems to be relatively uncluttered", relating to stimulus numerosity, for example) and examining

a display. The forced responses for each display can then be tabulated and the data used to identify areas of inadequate HFE design of displays (along the appropriate dimensions), remedy the inadequacies, or made use the data in trade-off analysis.

HECAD

Aume and Topmiller (1972) report a computerized design and evaluation tool called HECAD (Human Engineering Computer Aided Design). The purpose of HECAD is to avoided the necessity of building workspace mock-ups to evaluate complex design concepts.

HECAD is composed of two subprograms, INDICODE, which is based on an "Index of Electronic Equipment Operability" (developed by AIR), and DEWO (Deployment in Workspace). INDICODE (like the AIR Data Store) is a method of measuring workstation operability by estimating activation times and reliabilities of panel components (toggles, pushbuttons, etc.). The user of INDICODE specifies, via a CRT and lightpen, the components of a panel. The program then computes and prints the estimated time and reliability of each. The punched cards are used as inputs to the second program, DEWO. DEWO produces a deterministic output, and also requires that the user supply a definition of a single (3-D) workspace to be evaluated. Again using the CRT and lightpen, the HECAD user arranges the individual components (50 maximum) within the workspace containing less than 11 panels. The data cards are used to specify for each component:

- The component number
- Activation time
- Component dimensions
- For rotating controls, the initial angular setting

Task sequences are then entered. The tasks are simply the sequences of control or display use and are for the sole purpose of determining visual or motor transition times, of which there are three types, reaching movements, turning movements (for rotary controls) and eye travel. Times are computed from Methods-Time Measurement (MTM) formulas. The end point (of the eye, for example) for a given task serves as the starting point for a subsequent visual task.

The simulation is simply an execution of the tasks interacting with the components. The program determines the execution time of each task (visual, motor transitions), and performance reliability (product of reliabilities for use of each component), and counts the number of times each component is used during a task sequence.

The following are outputted by DEWO:

- Listing of panel equations
- Task sequence
- For each component
  - the identification number
  - the current location
  - the number of times component is used during a task sequence
  - activation time
  - performance reliability
- A summary table containing a listing of all actions during a task sequence (by limb, start and destination component)
- Task sequence results
  - number of actions per sequence
  - time that hands, eyes are active
  - communications times
  - total task time
  - task reliability
- The 30 longest transfer times are displayed on the CRT in order

This last output item, according to the authors, forms the basis for redesign decisions. If the user of HECAD wishes to rearrange components, he can do so simply by using the CRT, light pen and keyboard. He may then run the task sequence (or another task sequence) again to determine the effect of the rearrangement.

TX-105

A computerized technique similar to HECAD and developed by Boeing is TX-105 (Geer 1976), which has been developed to help evaluate workload of aircraft crews and to evaluate cockpit size.

Three subroutines comprise TX-105, which are used to calculate angles between the eye and points within a cockpit and then to compute linear and angular distances of eye and hand movements during task performance.

Inputs to TX-105 include:

- Cockpit geometry information
  - control locations
  - display locations
  - control and display labels
  - eye and shoulder reference points
- Task data
  - name
  - sequence of tasks
  - point to point sequence of tasks within the workspace

Outputs of the program are similar to those of HECAD and may be used in the same manner, as a design tool, or to assist in selecting a design concept which minimizes time

and motion requirements of operation. HECAD, however, provides an indication of system operational effectiveness in terms of human reliability (in addition to a measure of workload).

THERP

A technique that has been developed at Sandia Labs and reported by Meister (1971) and Geer (1976), is known as THERP (Technique for Human Error Rate Prediction).

THERP is a technique that predicts total system decrement as a function of estimated human error rates. The technique emphasizes two primary measures, the probability of error occurrence and the probability that error occurrence will result in system or subsystem failure.

There are five steps entailed in the use of THERP:

1. Defining the operation
2. Establishing and listing tasks
3. Estimating error rates per task
4. Predicting effect of errors on system performance
5. Deriving design modifications intended to minimize system failure rate

It is evident by the final step that THERP is intended to be used as a design tool.

Sources of data for THERP application are operational data (from similar systems or, if a redesign effort is underway, from the same system), laboratory studies, and subjective judgment (based on task analysis).

Once error rate and error effect data are estimated (by whatever means), the probability of system failure is estimated by compounding the data.

Two major assumptions of the technique are: (1) human errors that occur and have little or no effect on system failure rate are noncritical (and weighted O); and (2) errors are independent.

For subjective data that are used in the technique, a set of factors to be considered in estimating error rates per task are provided. These have been termed Performance Shaping Factors and are:

- Operator motivation
- Operator training experience
- Stress level
- Task difficulty
- Task redundancy

- Manner and use of job performance aids

Since the incidence of human errors on system performance is not considered to be binary, the probability that an error will cause system failure must also be estimated. This could be by expert judgment (design engineer perhaps) or by examination of failure mode effects and criticality analysis data.

TLA-1

Miller (1976) has described a computer program, created at Boeing, known as TLA-1 (Timeline Analysis Program - Model 1) which has as its purpose to estimate operator workload for task sequences within given flight scenarios.

The TLA-1 program is implemented in four successive steps. The first is that of scenario development. Here mission milestones are identified and event times estimated from mission flight plans, operations, manuals, etc. The second step is to derive task data. Tasks are categorized by subsystem and for each task, identification is made of:

- Estimated task duration time
- Channel activity (left foot operated, right foot, hands, external visual, internal visual, cognition, auditory or verbal)

These data are to be derived or estimated from operator's manuals, human performance data bases (reach times, eye fixation/rotation times, and so on), task analysis and task simulation. The third step in applying TLA-1 is the development of the task timeline. Worksheets are provided and tasks are sequenced. For each task, task name, identification number, start time and duration time are coded on the worksheet. Step four is simply to codify the data in a form suitable for keypunching.

When the program is run, the following data are derived:

- Task time intervals
- Channel group workload
- Weighted average channel workload (average channel workload)
- Mean workload
- Workload variance
- Workload standard deviation

Output data (as requested by the user), can be directed to tape (for data storage), printer and/or a graphics plotter. Printer output consists of:

- Mission Scenario Report - lists specific phases and associated events, procedures and tasks. This report is quoted as having two purposes: (1) task and procedures documentation; and (2) verification that all tasks are being performed during a given time interval.

- Crewman Workload Profile Report - provides channel, channel groups and average channel workload for each task time interval (stated as a percentage. If this figure is greater than 100 percent either an input error has occurred or a work overload condition exists).
- Crewman Workload Summary Status Report - for each channel, channel group and weighted average channel over a phase, the following are printed:
  - mean workload
  - workload variance
  - standard deviation
- Task-Channel Activity Report - lists all tasks that contribute to a channel workload exceeding a specified threshold (specified upon input of data, 70% for example).
- Subsystem Activity Report - lists tasks that contribute to channel overload ordered by subsystem operation.
- Subsystem Activity Summary Report - Summarizes results of the Subsystem Activity Report.
- Task List Report - provides an "easy-to-read" task catalog.

Output of the graphical plotter includes:

- Channel Activity Summary Plot - provides a bargraph (for a specific phase within a mission) of channel workload mean and/or standard deviation.
- Workload Histogram Report - plots (in a histogram form) channel workload, channel group workload and/or weighted average workload as a function of elapsed mission time.
- Workload Summary Plot - bargraph of specified crewmembers channel activity mean, standard deviation or weighted average channel workload.
- Mission Timeline Plot - task timeline showing when a task sequence is in effect over total mission time.

TEPPS

TEPPS (Technique for Establishing Personnel Performance Standards) reported by Geer (1976) and Meister (1971) is a computerized technique which estimates the probability of task accomplishment and task performance time (as THERP and HECAD). The technique is applied in five steps using two submodels. The first submodel, the Graphic State Sequence Model (GSSM), is heavily relied upon by TEPPS. It is, in essence, a functional flow diagram of the ways in which system requirements (or operations) may be accomplished. The second submodel is the Mathematical State Sequence Mode (MSSM) which is a computer program which handles the analysis of the data. The MSSM is viewed as a reliability equation, that is, the MSSM is essentially a reliability block diagram.

The six steps of TEPPS application are as follows:

1. Describe the system
2. Develop the GSSM in terms of personnel-equipment functional (PEF) units
3. Determine predictive data for GSSM units
4. Apply predictive data to GSSM
5. Develop MSSM from GSSM and predictive data
6. Implement computer program to analyze/derive system reliability

Data for item three above is derived by a paired comparison technique which estimates performance probabilities and time requirements for each PEF.

The MSSM model (in effect the mathematical equivalent to the GSSM with associated success probabilities) simply determines the products of all the PEF probabilities of success and sums PEF performance times.

It is possible to use TEPPS both as a design tool and an evaluation tool. It's ultimate utility is probably that of design.

WAM

The Workload Assessment Model (WAM) of CAFES uses a timeline of mission tasks in order to identify areas of operator overload. The objective of WAM is to estimate the effects on operator workload, due to crew function allocations, early in a systems developmental history. Further, where workload problems are revealed by WAM, they can be lessened by functional reallocations, increased automation, procedural changes, etc.

Procedure for WAM application is as follows:

- Prepare a mission profile and scenario
- Construct a mission phase chart (mission divided into phases)
- For each mission phase, identify tasks to be performed and estimate task times
- Prepare a mission phase timeline
- Identify channels used for each task (visual, manual, cognitive, auditory, verbal)
- Prepare data for WAM execution

WAM outputs tabular and plotted statistical summaries of crewmember workload in terms of channel activity per unit time (specified by the user, six seconds is the nominal recommended time segment). WAM also outputs averages, standard deviations and variances for channel workloads over all time segments for each mission phase.

SWAM (Statistical Workload Assessment Model) is a development of WAM that computes workload as a function of required task time vs. time available for each

operator channel. SWAM automatically identifies high workload conditions by computing, per time segment, percentage of channel utilization (percent of time that a channel is active over the specified time segment duration), and comparing the value (percentage) to an input workload threshold.

The SWAM user can optionally select a task shifting feature of the program, e.g., where the workload threshold is exceeded, SWAM will determine if any tasks can be shifted (as specified on input), without causing overloading in the time interval(s) to which tasks are shifted.

Specific output of WAM is as follows:

- Average channel workload for each and combined channels
- Sequenced list of task start time, duration time and end time
- Shifted tasks and amount of time a task was shifted
- System activity times (system activity defined by subsystem ac time, interval time, and percentage of activity time for total mi: time)
- List of tasks contributing to overload when threshold is surpassed
- Workload for each channel
- Workload for combined channels
- Workload standard deviation for each and combined channels over total mission time.

Simulation Models

A group of computerized simulation models have been developed by Siegel and Wolf (Seigel and Federman, 1971; Siegel and Wolf, 1969; Meister, 1971; Geer, 1976; Siegel, 1977). These three models are:

1. Siegel -Wolf 1-3 man model (SW 1-3)
2. Siegel -Wolf 4-20 man model (SW 4-20)
3. Siegel -Wolf 20-99 man model (SW 20-99)

The models are all similar in terms of intended uses, inputs and outputs. The models sequentially simulate task performance of all operators. The intended use (goal) of the models is to identify areas of operational overload (the models assume that operator overload is a basic element in degrading overall system performance). Stress is viewed as a basic component of overload. Basic inputs to the models are:

- Mission parameters
- Time available to complete tasks
- Operator characteristics (speed, stress thresholds, motivation, etc.)

- Task characteristics
  - sequence
  - essentiality
  - precedences
  - execution time
- Time distributions/task success probability distributions

The last entry above makes the SW models unique in character. In the course of a simulation, the time that is required to complete a task is drawn pseudo-randomly from a distribution (normal, Poisson, Weiball, at the user's option; standard deviations are also input at the users specification and option). Output consists of mission time and success distributions as a result of updated mission simulations with outputs dependent upon pseudo-randomly drawn inputs.

Simply stated, the method of simulation is thus:

- Operator encounters a task to perform
- Task urgency computed (time remaining to complete task sequence)
- Stress computed (as a function of urgency)
- Task execution time drawn from a distribution
- Probability of successful task completion drawn randomly from a distribution
- Data tabulated and stored
- Repeated until all tasks are performed
- Repeated until all iterations are performed
- Results reported

Stress enters into the simulation via the determination of task execution time, time left to complete a mission and task probability of success. Stress increases with decreasing availability of time. Probability of successful task completion increases with stress to a point. As a threshold is reached (specified in input), however, the probability of successful task performance drops rapidly and task completion time increases. Prior to stress having reached the threshold, the computer simulation may omit or delay non-essential tasks, thereby reducing stress.

Since the sequence of tasks is run many times with various results (depending on the values drawn from the distributions), output data is, for the most part, simply a matter of counting events and outcomes, and mission times.

The program produces as output data:

- Total time expended
- Peak stress encountered during the simulations

- Final stress encountered
- Probability of task success
- Average waiting time (for another operator to complete a task)
- Number of subtasks ignored
- Number of tasks not successfully completed
- Task sequence (or mission success) probability (successful task sequences/total task sequences)

The larger models have some additional capabilities such as the ability to simulate team cohesiveness, aircraft turbulence, etc. Table 3 gives an indication of the complexity of the models by listing input data to the SW 4-20 man model (adapted from the Human Reliability Prediction Systems User Manual, December 1977).

Data sources for input data are largely subjective, based on task analysis; however, since probabilities of successful task performance and task execution times are drawn pseudo-randomly from distributions, it seems that error may tend to be minimized.

<u>HOS</u>

Another computerized technique that simulates human behavior in a system is the Human Operator Simulator (HOS) (Strieb, Glenn and Wherry, 1978, and Meister, 1971). HOS is a design and an evaluation tool that is designed for use relatively early in a systems development.

HOS simulates:

- Information absorption
- Information recall
- Mental computations
- Decision making
- Anatomy movements
- Control manipulations
- Relaxation

Information absorption in HOS can be made visually and tactually. As an operator reads a device, time is expended; when the time expended (in terms of number of micro absorptions) reaches a threshold, the information is deemed to have been absorbed. For continuous and discrete displays with more than seven settings, an absorption error term can be introduced (by the user) and will be used by HOS in computing the operator's perceived value or setting of the device read.

Information recall is essentially a function of:

TABLE 3
SW 4-20 MAN MODEL DATA

Average crewmember aspiration
Average crew pace
Average duration of scheduled event
Average psychological stress threshold
Average repair time
Average standard deviation of repair
Average standard deviation of emergency
Effectivity of stress
Number of calories required by crewmen (per day)
Catnap length
Duration time of emergencies
Duration time of repairs
Emergency event data set
Repair event data set
Number of duty shifts
Expected energy consumption
Expected energy consumption for emergency
Essentiality (task)
Emergency essentiality
Essentiality threshold
Event type number
Event number in family
Event hazard class
Event hazard class (emergency)
Printout option indicator array
Event code
Prerequisite event
Equipment list
Consumable rate of expenditure (units/hours)
Consumable rate of expenditure (units)
Consumable rate of expenditure (units)—emergencies
Number of repair events
Physical capacitation fraction
Derating constant
Event end type
Initial level of consumables (units/hours)
Initial level of consumables (units)
Threshold consumables (units/hours)
Threshold consumables (units)
Mental load
Mental load for emergency
Maximum sleep
Crew composition array
Average number of man days per incidence of physical incapacitation
Number of iterations
Number of days
Number of days between emergencies
Maximum number of days
Duty shift
Equipment used array
Number of scheduled events
Number of men required by type
Number of men required by type for emergency
Next event number for each alternative
Average duration of physical incapacity
Percent fully qualified in primary specialty
Percent moderately qualified in primary specialty
Percent unqualified in primary specialty
Probability for each alternative path
Cross training probability table
Equipment reliability
Intermittent reliability
Repair touchup code
Sea state/turbulence
Standard deviation of body weight
Number of hours since last eight-hour sleep period
Percent fully qualified in secondary specialty
Percent minimally qualified in secondary specialty
Percent unqualified in secondary specialty
Earliest starting time allowed
Fatigue threshold
Time limit by which event must be completed
Consumable threshold set identifier (units/hours)
Consumable threshold set identifier (units)
Threshold set for consumables below which event is ignored (units/hours)
Threshold set for consumables below which event is ignored (units)
Threshold set for consumables below which emergency is ignored (units/hours)
Threshold set for consumables below which emergency is ignored (units)
Number of hours worked after which no new work assignment is made
Number of hours worked after which no new work is authorized
Mean body weight
Physical capability constant

- HAB strength - habit strength, the operators confidence in the knowledge of a device's value (a function of the number of micro absorptions (time) in having read a device)
- time since a device was read.

HOS computes a recall value (termed a probability of recall) and compares the number to one drawn randomly from a uniform distribution; by comparing the values, HOS determines if the information is remembered, forgotten, or, if the values are sufficiently close, a new random number will be drawn and the comparisons renewed. This method applies only to information absorbed. HOS assumes that control and display locations, methods of control activation, etc., are always recalled (since HOS simulates a trained operator's performance).

HOS simulates mental calculations for such things as distance that can be covered with remaining fuel. HOS determines the information required; if any is not recalled, appropriate devices may be reread in order to obtain the data.

Simply stated, operator decisions are simulated by HOS by acquiring the data required to make the decision (as input by the user). If the information (and/or events) satisfy conditions that are required in making a decision, the decision is made and a set of appropriate actions follow. In certain circumstances, where the conditions are not suitable (e.g., a required subsystem or control is not active), HOS will simulate the operators behavior in enabling the subsystem.

Anatomy movements are also simulated by HOS. Where an operator movement is required, HOS determines the channel to be used as a function of the position of the object, nominal and current channel position (hands and feet positions) and the processes of any concurrent body movements (if the right hand is already engaged in a control activation, for example). For the body part selected, HOS computes a "time charge" for that action as a function of distance to move that body part from point A to point B. If, for example, the right hand is engaged, and a movement is required that cannot be performed by the left hand, HOS will simulate the left hands taking over the current right hand activity, thereby freeing the right hand.

Once a control has been accessed by an operator channel, control manipulation time and effect is simulated by HOS according to a variety of self contained formulas and data input by the user. When body parts are not active, HOS moves them to a comfortable position thus simulating relaxation.

A good deal of data is required for the use of HOS, including: mission scenario data, detailed task data, control and display locations, method of control activation, display

information, operator procedures, hardware procedures, beginning and/or nominal system and operator status (hand locations, subsystem activities, etc.), and information absorption times.

HOPROC (Human Operator Procedures) is the computer language which is used to define the input data to the computer. HOS performs the simulation, analyzes the data and provides output such as the following:

- Timeline analysis (the "snapshot" interval of time)
- Channel loading within each snapshot interval
- Channel activity statistics related to each device
- Device usage time of specific actions (time spent moving, manipulating, recalling, etc., for each device)
- Link analysis (transition times, link frequencies)

Clearly, HOS is concerned with the time history of the system, specifically as it relates to momentary operator workload and device usage.

SAINT

SAINT (Systems Analysis of Integrated Networks of Tasks), as reported in the literature (Ducket and Wartman 1976, Wartman and Ducket 1976, Geer 1971, Hann and Kuperman 1976), uses, as its basic element, the task to aid in the design and evaluation of developing systems. Currently, three SAINT programs exist (SAINT I, II and III). The latter versions have been improved and expanded from SAINT I to simulate changing system conditions such as fuel remaining, altitude, etc.

To apply SAINT, the user must first generate a task network (for up to ten operators). A procedure for generating these networks is provided; basic (stepwise) inputs are:

- Identify sequence of tasks and task characteristics
    - identify precedence relationships (task dependency)
    - connect precedent relationships by key branches (connecting lines) which becomes the basis of a network
    - assign task numbers
    - specify task inputs; is precedent task(s) that must be completed prior to task "release" (note: first task of a sequence is labeled "source task")
    - provide task description and code
    - specify task duration (can be drawn from a distribution of times, if desired)
    - identify task outputs which represent a branching of decision
        (1) deterministic options
        (2) probabilistic (randomly drawn from a distribution)
        (3) conditional—take all options for which conditions are satisfied

- Identify resources ("a non-consumable commodity that is required for the performance of one or more tasks")
  - define resource availability
  - identify resource by code
  - identify resource requirements for task completion
    - (1) all specified resources are required
    - (2) a subset of all specified resources is required
- Identify information attributes
  - information flow
  - information attributes and values
  - information requirements for each task
- Specify task statistics
  - specify the desired statistics for output (task completion time, etc.)
- Specify task priority (numerical value)
- Identify resource attributes
  - operator characteristics (weight, level of intelligence)
  - equipment (mode of operation, resistance)
- Specify moderator functions (specifies system status variable that may affect task performance times, for example, waiting for another operator)
- Identify system attributes
  - equipment
  - equipment response times
- Specify state variables (fuel supply status over time, for example)
  - plots (of status over time)
  - tables (of status over time)

Like the Siegel-Wolf and other models, the task analysis and subjective judgments are required to provide these types of input data.

The method simulates system and operator performance much in the same manner as the Siegel-Wolf models, i.e.:

1. A task is initiated
2. Factors affecting task completion time are examined
3. Task completion time (selected from a distribution or nominally) is modified by those factors (waiting, time constraints, etc.)
4. Subsequent task(s) to be executed is/are selected (probabilistically, as a function of priority or time, or deterministically)
5. Factors affecting task "release" are surveyed (task dependency, etc.)

and the sequence continues until the mission is over. The mission itself is iterated a specified number of times and mission time distributions can be developed.

The use of SAINT can specify various outputs of the simulation, histograms, plots, summary statistics, etc. Of principle interest are mission success data, task completion time data (individual tasks) and mission times.

Anthropmetry

Anthropometry is defined as the technology of measuring human physical traits, primarily size, mobility and strength (Hertzberg, Human Engineering Guide To Equipment Design, 1972). Parametric data for engineering use are usually presented in percentiles. Elimination of one percent at both ends of the distribution results in accommodation of 98% of the population. Designers, according to Hertzberg, should attempt to accommodate at least 90% of the population and should strive for 98%.

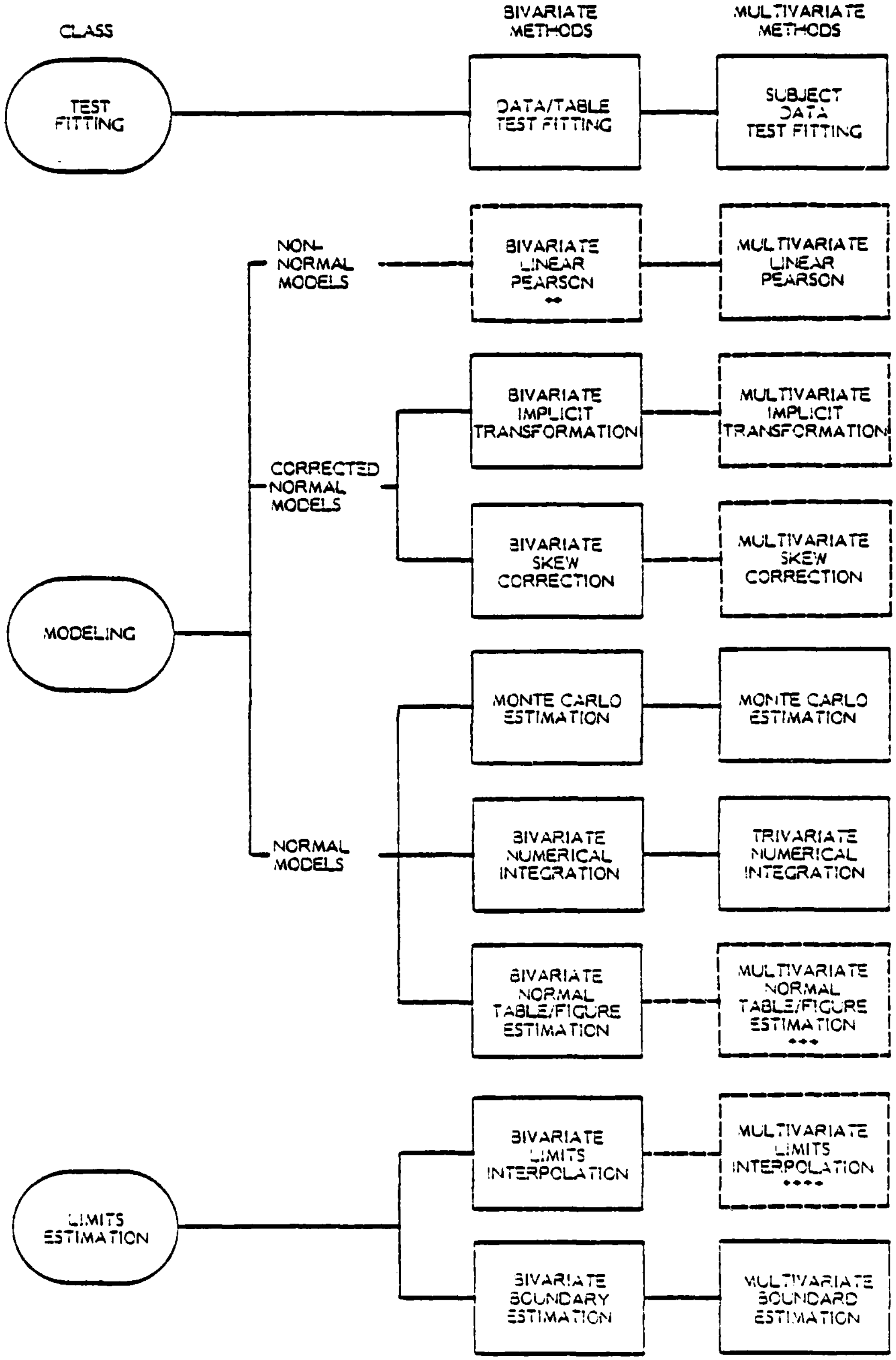
In the application of anthropometric data to design, the same person will differ in terms of percentile for different dimensions, e.g., a man at the 5th percentile in terms of arm reach may be at the 50th percentile in some other dimension. Bittner and Moroney (1974) note that the actual proportion of the user population accommodated by a design based on using a range of anthropometric dimensions is not readily apparent due to interactions among dimensions. These authors cite previous research which indicated that the magnitude of the population excluded when using a range of dimensions has been reported to be as high as 52% for the 1964 population of Naval aviators. It was concluded that design of workspaces without awareness of the interaction between anthropometric variables ultimately leads to a considerable reduction in the size of the accommodated population.

Research directed at this problem at the Naval Pacific Missile Test Center initially focused on surveying and evaluating available methods for calculating the accommodated proportion of the population. Table 4 (from Bittner and Moroney, 1974) presents the methods identified and Table 5 (same source) contains results of an assessment of the alternate methods.

The latest anthropometric source book is that published by NASA (July 1978). Although designed in part to provide NASA and its contractors with material on the weightless environment, it also offers all available anthropometric data with size range projections for the 1985 population. Of particular interest is material on the variability in human body size which points out to engineers the extent of human body size variability to be considered in the modification and design of man-machine systems. Additional information on arm-leg reach and workspace layout, including data for the adjustment of workspaces, etc., due to anthropometric differences and environmental conditions is

TABLE 4
CLASSIFICATION OF ACCOMMODATED PERCENTAGE METHODS

(Bitner and Moroney, 1974)



NOTES:

** Broken lines denote methods not yet validated by practice
*** Feasible but not practical beyond 3-variates
**** May have potential, but undeveloped approach

TA .5
ASSESSMENT OF ALTERNATE METHODS

Method	Description	Nature	Requirements	Accuracy	Limitations	Advantages
Monte Carlo Estimation (Multivariate Normal)	Computer-generated quasi-random samples from a multivariate normal populations with a correlation matrix, matching feature correlations are compared against input restrictions. The ratio of the number of accommodated samples and the number of sample cases (NCASES) forms the estimate of the accommodated percentages.	Estimated Approximation of population parameters.	Requires $(NV^2+NV)/2$ correlation coefficient table and 2NV table of means and standard deviations for NV features; computer for practical applications.	Limited by accuracy of mean; standard deviation and correlation estimates, and Monte-Carlo sampling accuracy, i.e.,	To feature sets where mean, standard deviation and correlation estimates are available.	Requires least data of multivariate models; can be applied when the number of variables is large (e.g., NV 25). Implemented in an interactive version of FORTRAN.
Multivariate Normal Numerical Integration	The volume of a multivariate normal distribution--with correlations--is divided into a large number of small rectangularly based volumes. Rectangular approximations to each of these volumes is added together if within exclusion bounds. The resulting sum is the P_j.	Approximation of population parameter.	Requirements are same as for Monte Carlo method.	Limitations parallel that of Monte Carlo sampling inaccuracies replaced with errors due to numerical integration.	Same as Monte Carlo; but also limited to relatively small NV as the number of steps each dimension is discretized, then exponentiated by NV.	Requires least data of multivariate models; is most accurate normal approximation for small NV (3). Implemented in FORTRAN.
Normal Table/Figure Estimation	Figure and tables, prepared by numerical integration are used in "Look-up" fashion for amounts excluded by application of exclusion criteria.	Approximation of population parameter.	Requirements same as for Monte Carol method.	Inaccuracies include those of multivariate numerical integration (as that was the method of generation) also subject to interpolation inaccuracies.	Current tables/figures limited to bivariate populations; also has limitations of multivariate normal numerical integration method.	Requires least data of bivariate models and can be applied without a computer.
Interpolation Estimates	In the bivariate case, P_j is estimated by interpolation between the proportion that would be accommodated if the feature correlation is zero and that if the correlation were (±)1 where the sign (±) is that of r. The end points are 0 and 1, respectively, and the integration is linear in terms of r^2.	Approximation of population parameter.	Requirements same as for normal approximations (e.g., Monte Carlo).	Empirical studies have shown that the integration estimate differs from the normal model by less than 5% relative error.	Current method limited to bivariate populations with estimates of mean, standard deviations, and correlation. (Preliminary work has indicated possible multivariate extensions.)	Can be rapidly computed with--at most--univariate normal tables. Estimates can be made in situations not covered by current bivariate normal tables.
Boundary Estimation	For a multivariate population with restrictions which exclude a proportion (a_i) on each variable separately, the accommodated percentage is less than $1 - a_i$. Hence, an upper bound estimate is $P_u = 1 - a_i$.	Estimate of upper bound of P_j.	Estimate of the proportion excluded by limits on each variable separately, i.e., a_i for i = 1, 2, , NV.	Bound accurate to accuracy of a_i estimates.	Requires only estimates of the a_i for all i.	Does not require estimates of the correlations between features or put restrictions on distributions; simple to calculate.

ʟLE ,
(Continued)

Method	Description	Nature	Requirements	Accuracy	Limitations	Advantages
Test Fitting	S's feature measurements are stored as "feature vectors." Elements of each S's vector or the vector of groups like S's are compared, element by element, with exclusion criteria to ascertain accommodation. The number passing all criteria is counted and a percentage calculated.	Statistical estimate of population parameters.	For Bivariate Table method, require $(NV^2 + NV)/2$ tables for NV features taken as pairs. For multivariate studies, require storage for sample S's by feature table: PxNSUBxNV cells. Sorting device (e.g., computer) for large-scale studies.	Limited by proportion (P) of population sampled, by measurements, by representativeness and recency of sampling. Bivariate Table Test fitting also limited by table resolution.	To "well-defined" sample data; i.e., where features of interest were measured on S's representative of population of interest.	Most accurate method (potentially). (Bivariate tables do not require a computer for application.)
Linear Pearsian Model	Based on estimates of first four moments of S feature distributions and their correlation matrix, a multivariate model is determined which matches all input parameters. Percentage accommodated is then established by study of the effects of restriction on the model.	Approximation of population parameter.	Requires table of $(NV^2 + NV)/2$ correlation coefficients and a 4NV table of first four moments for each parameter. Computer for practical applications.	Limited by accuracy of parameter estimates, closeness of linear regression model to population, and accuracy of method to evaluate the model.	To feature sets where first four moments and correlations can be estimated. (Technique not currently implemented or proven by experiment.)	Input feature parameters need not be determined on a common population. Second most accurate method (?).
Implicit Transformation Model	Restrictions on each feature distribution is converted into "equivalent Z-score" restrictions on a univariate normal distribution. Effect of restrictions on the population are estimated by applying the the Z-score restrictions to a normal model with a correlation matrix matching the feature correlations.	Approximation of population parameters.	Requires table of $(NV^2 + NV)/2$ correlation coefficients and (3NV) table of percentiles (e.g., 2-50-98% table for each variable). Note: requires method for estimating restrictions on a multivariate normal model.	Limited by accuracy, representativeness, and recency of percentile data limited by closeness of implicit model to population; by accuracy of normal model evaluation accuracy; and by number of percent steps/interpolation accuracy limitations.	To feature sets where percentile and feature correlations can be estimated.	Input feature parameters need not be determined on a common population. Second most accurate method (?).
Skew Correction Models	Restrictions on each feature (e.g., x) are converted into Z-score values by equation Z-(x-x)/a; where a is the difference between the mean (x) and the 5th or 95th percentile value for feature x depending on whether the deviation from the mean is negative or positive, respectively. Effects of restriction on the population are estimated by applying Z-score restrictions to a normal model with a correlation matrix matching the feature correlations.	Approximation of population parameter.	Requires table of $(NV^2 + NV)/2$ correlation coefficients and a 3NV table of means, 5th and 95th percentile values for each of the NV variates. Note: requires method for evaluating restrictions on a multivariate normal model.	Limitations parallel those of implicit transformation methods with the inaccuracy of the skew corrections replacing the percentile-steps/interpolation accuracy limitations.	To feature sets where mean, 5th percentile, and feature correlation estimates are available.	Corrects for non-normality with data usually available. More accurate (generally) than non-corrected normal approximations.

included. Volume II of the same NASA publication summarizes the results from anthropometric surveys of 61 military and civilian populations of both sexes from the United States, Europe and Asia. It is primarily a handbook of tabulated dimensional anthropometric data and is the most comprehensive source of summarized body-size data available at present. Volume III contains 236 annotated references related to the field of anthropometry.

In the design of crew stations, two-dimensional drawing board manikins are important aids. Volume I describes the USAF two-dimension manikin developed by the Aerospace Medical Laboratory based on 1980-1990 anticipated body size distribution of USAF fliers. The manikins are accurate in at least 25 body size dimensions important in the layout of crew stations. Consideration of variability in body proportions can be taken into account with the use of alternate limbs. Additional sources of anthropometrical and related data are as follows:

- Head and Neck Mobility of Pilots Measured at the Eye, Champion, 1974
- "The Adult Human Hand: Some Anthropometric and Biomechanical Considerations", Garrett, 1971
- The Female in Equipment Design, Glumm, 1976
- Muscles: Testing and Function, Kendall, et al., 1971
- Anthropometry and Kinematics in Crew Station Design, Kennedy, 1972
- Designing for Muscular Strength of Various Populations, Kroemer, 1974
- Muscular Strength of Women and Men: A Comparative Study, Laubach, L., 1976
- Statistical Concepts in Design, McConville, J., and Churchill, 1976
- Engineering Anthropometry Methods, Roebuck, J.A., et al., 1975
- Anthropometry of Air Force Women, Clauser, et al., April 1972
- Anthropometry of U.S. Army Aviators, Churchill, et al., 1970
- Selected Anthropometric Dimensions of Naval Aviation Personnel, Moroney, et al., 1971
- The Body Size of Soldiers, R. White and E. Churchill, 1971
- Horizontal Static Forces Exerted by Men Standing in Common Working Positions, Robinson, 1971
- Anthropometry of the Hands of the Male Air Force Flight Personnel, Garrett, 1970
- Anthropometry of the Air Force Female Hand, Garrett, 1970
- Anthropometric Dimensions of Air Force Pressure-Suited Personnel Work Workspace and Design Criteria, Alexander, Garrett and Flannery, 1969

- Databook for Human Factors Engineers: Volume I - Human Engineering Data, Kubokawa, et al., 1969
- Clearance and Performance Values for the Bare-Handed and Pressure Gloved Operator, Garrett, 1968

CAR

Several computerized methods to determine if an operator can fit, anthropometrically, into a workspace are available. CAR (Crewstation Assessment of Reach) (Geer 1976, Bittner 1976) was developed as a Monte Carlo model for examining pilot anthropometric data. The model entails a link man model and an adjustable workspace model. Given the workspace model, CAR computes the percentage of aviators that can be accommodated by that workspace (cockpit). CAR provides two submodels to the user, (1) Monte Carlo Simulation Model (MCSM), and (2) Crewstation Analysis Model (CAM).

The MCSM option generates sample aviator anthropometric data. MCSM randomly generates 12 anthropometric measures for a user specified number of sample aviators. These measures are translated into 19 man-model links.

CAM evaluates a deferred crewstation geometry using crewmen sample generated by MCSM. Output is the percentage of crewmen that can be accommodated by the input crewstation geometry.

The cockpit analysis model determines the percentage of population excluded based on geometric parameters of the workspace. Components of this model are:

1. Pilot link system
2. Pilot sample generator
3. Seat-cockpit layout
4. The testing component

COMBIMAN

Evans (1976) has reported a computerized technique known as COMBIMAN (Computerized Biomechanical Man-Model) which is a design aid to anthropometrically fit operators to workspaces. COMBIMAN was built to aid in the design and evaluation of aircraft workspaces but claims to be applicable to any workspace. Specific applications are:

- The evaluation of existing workspaces
- Design and evaluation of new workspaces
- Personnel selection criteria for workspaces
- Mapping of external visability plots

COMBIMAN consists of two submodels, the man/model and the workspace design model. The man/model consists of a 33 link skeletal system where link length can be specified either by the user or automatically via reference to an anthropometric data base. The workspace model permits the development of a three dimensional workspace containing operating panels of three to six vertices. The workspace can be established using either punched cards or use of a CRT, light pen and keyboard.

User supplied data (in addition to workspace dimensions) can be:

- Direct anthropometric measures of subjects
- Data base percentages
- Combinations of measures and data base measures
- Required population dimensions (to fit a workspace)
- Required or established maximum rotational angles
- Bodily restrictions such as clothing

The three important subprograms of COMBIMAN are: (1) the interactive graphics program (output program); (2) the COMBIMAN Anthropometric Data Base Maintenance Program (CBMAN); and (3) the COMBIMAN Workspace Data Base Maintenance Program (CBMWM).

The basic outputs of COMBIMAN are indications of successful or unsuccessful reaches, given a specific workspace and input anthropometric data of an operator. The dimensions of the man/model may be varied using the keyboard and light pen, thereby determining minimum and maximum reach distances of the simulated operator.

CGE

The CGE model of CAFES is used to identify and analyze cockpit reach characteristics and test cockpit compliance with military specifications and standards. CGE is applied in two steps. First, input data are prepared, including:

- Cockpit geometry data
- Controls data
- Eye reference points data
- Task sequences data
- Control shapes data

Outputs of the CAD model of CAFES can be implemented as partial input to CGE. The second step entails specifying output for the DMS/CGE interface model.

CGE uses mathematical routines to simulate activities of a variable sized man-model. Output of CGE includes:

- Physical and visual interferences
- Unfeasible reach tasks
- Crew station compliance with military specifications and standards
- Feasible tasks accomplished

ORACLE

Operators Research and Critical Link Evaluation (ORACLE) (Meister, 1971) is a computerized diagnostic and evaluation tool of workload. The model simulates the input and processing rates of information nodes and links in an information flow system. ORACLE is not behaviorally oriented, but may have application to man/machine systems if an assumption is made that nodes may be modeled to represent human operations.

According to the developers, the uses of ORACLE are:

- The determination of the number and types of personnel required for a task mixture (man/machine allocations) and system configuration
- The determination of design change effects on system effectiveness
- The identification of critical elements (paths) in an operational sequence
- Measurement of the effect of degradation of individual system functions

Input data to ORACLE include:

- Input rates for information units (messages per unit time)
- Message initiation times
- Message response times
- Message priorities
- Probability of an events occurrence based on equipment availability and reliability criteria

The data are used by the program to provide a timeline history of system operations. Specific outputs include a prediction of total processing time required for a given sequence of events and the identification of queues of information representing information overload at nodes.

HFTEMAN/HEDGE

Two guides for planning, implementing and analyzing HFE Test and Evaluation are HFTEMAN (Human Factors Test and Evaluation Manual) (Malone and Shenk, 1977) and HEDGE (Human Factors Engineering Data Guide for Evaluation) (Malone and Shenk, 1978).

HFTEMAN is primarily directed towards developing an HFE T&E plan. HFTEMAN is divided into three volumes:

- Data Guide - contains guidelines concerning what to evaluate for classes of equipment and types of tests
- Support Data - contains criteria expanding the guidelines and criteria in the Data Guide
- Methods and Procedures - contains guidance on how to design, set up, conduct, and analyze data obtained in implementing the HFE T&E plan

The Data Guide provides eight steps to perform an HFE OT&E and ten steps to perform an HFE DT&E. The first seven steps are identical for both and are:

1. Inspect the test item and review documentation
2. Identify the type of test(s) to be performed — test types are:
   - Operability
   - Maintainability
   - Transportability
   - Habitability
   - Portability/usability
   - Erectability
3. Identify the class in which the test item belongs — equipments are classed in the Data Guide as being:
   - Vehicles (land, sea, air)
   - Weapons (individual, missiles, etc.)
   - Electrical optics
   - Support, supply and service
   - Personnel support
4. Identify pertinent use conditions to be considered as test conditions
5. Identify user activities and tasks
6. Identify equipment components associated with user tasks
7. Identify potential HFE problem areas associated with equipment components

The final step for HFE OT&E is:

8. Prepare a checklist or questionnaire to be used in observing or sampling fleet personnel performing with the item

The final steps for HFE DT&E are:

9. Select criteria (from support data volume)
10. Select test methods (methods and procedures volume)
11. Formulate HFE test plan using selected tests and test criteria

Design criteria for HFE considerations such as location and arrangement, sizes and shapes, direction and force, information, visibility, use conditions, and safety are provided

by equipment components (for example, controls, displays, workspace, doors, hatches, passageways, etc.). These criteria are provided in the Data Guide and Support Data volumes.

The methods and procedures volume contains data on how to conduct various HFE T&E evaluations. Specifically, this volume is comprised of the following evaluations:

- Design Evaluations
  - visibility
  - speech intelligibility
  - workspace and anthropometrics
  - force torque measurements
- Performance Evaluations
  - task checklists
  - error likelihood analysis
  - team performance evaluations
  - training evaluation
- Maintainability Evaluations
  - equipment and facilities
  - maintenance safety
  - maintenance information
  - maintenance actions
  - accessibility
- Habitability Evaluations
  - lighting
  - noise measurements
  - toxic hazards
  - environmental measures
  - vibration measures

HEDGE was developed for the U.S. Army Test and Evaluation Command (TECOM) and defines the Test Operating Procedures (TOPs) for the evaluation of Army materiel. HEDGE is, however, applicable to a large variety of equipments.

HEDGE is divided into two parts. Part 1 defines a number of HFE T&E procedures. Part 2 contains design criteria (in much the same manner as HFTEMAN). HEDGE describes the preparation for an HF equipment evaluation and provides specific test procedures for:

- Lighting evaluation
- Noise measurement
- Vibration measurement
- Atmosphere composition measurement
- Temperature, humidity and ventilation measurement
- Visibility measurement
- Speech intelligibility

- Workspace and anthropometrics measurements
- Force/torque measurements
- Design checklists
- Panel commonality analysis
- Maintainability assessment
- Individual performance assessment
- Error likelihood analysis
- Crew performance assessment
- Information systems assessment
- Training assessment
- Workload assessment
- Task checklists
- Questionnaires and interviews
- Dexterity
- Clothing and equipment

HFTEMAN and HEDGE represent roughly 22 separate HFE T&E techniques that have been grouped into an entire HFE T&E procedure. These two procedures also provide a series of data collection forms as an aid to the implementation of individual measurement and analytic techniques. Sample task checklists, design checklists and questionnares/interviews are also provided.

HFE design checklists are used as a tool to identify areas where HFE design criteria and HFE design principals have been violated. Checklists are constructed from sources such as MIL-STD-1472, HFTEMAN, HEDGE, Requirements Analysis, and so on. Examples of checklists are provided in Tables 6 through 11 (from Malone and Shenk, 1978). HEDGE and HFETEMAN provide detailed criteria for system components relating to:

- Labels, manuals and markings
- Steps, ladders
- Railings, handholds
- Doors, hatches
- Controls
- Displays
- Workspace
- Communicators
- Handles
- Optics

TABLE 6
HEDGE TRAINING DEBRIEFING QUESTIONNAIRE

Test Title | Date
Name | Grade/Rank

1. List your military occupational specialty (MOS).

2. How long have you had this military occupational specialty?

   __________ years

   __________ months

3. In the space below, list school training you have had in this military occupational specialty.

4. Which test item component did you use?

5. Did you encounter any problems during the test which you attribute to insufficient training? If yes, explain. Yes No

6. Did you understand all phases of your training? If not, explain. Yes No

TABLE 6
(Continued)

7.	Do you think it takes any special skill to operate the equipment you used? If yes, state the special skill.	Yes	No
8.	Would you like any additional training on the test item before you are assigned to operate it in a tactical unit? If yes, specify additional training.	Yes	No
9.	State in your own words how your training could be improved.		

TABLE 7

PRELIMINARY HF ANALYSIS

Test Item ______________________ Evaluator ______________________

Station ______________________ Date ______________________

Selected Tasks (from Task Checklist)	Factors to be analyzed in the HFE Subtest			
	Environmental Conditions	Equipment Characteristics	Test Participant Characteristics	Performance Measures

TABLE 8

COMMONALITY ANALYSIS DATA FORM

PANEL A ______________________ DATE ______________________

PANEL B ______________________ EVALUATOR ______________________

SYSTEM ______________________

CONTROL/DISPLAY	PRESENCE		CHARACTERISTICS							COMMENTS
	Unique?	Present - Both*	Location	Type	Size	Label	Arrange	Color	Operator	

* If not unique and present on only one panel - indicate that panel as A or B.

TABLE 9

WORKLOAD ASSESSMENT FORM

ITEM ______________ TEST FUNCTION ______________ DATE ______________

STATION ______________ EVALUATOR ______________

CONDITIONS ______________

CRITICAL TASK	TIME REQUIRED	ADDITIONAL TASKS CONDUCTED SIMULTANEOUSLY	EFFECTS OF TIME DELAYS IN TASK COMPLETION	OVERLOAD PROBLEMS	UNDERLOAD PROBLEMS

TABLE 10

DESIGN CHECKLIST

Test Title ______________________________

Test Project No. ____________________ Date ____________

DETAILED DESIGN CONSIDERATIONS	YES	NO	N/A	COMMENTS

YES = Adequate NO = Inadequate N/A = Not Applicable

TABLE 11

TASK CHECKLIST

Test Title ____________________

Test Project No. ____________________ Date ____________

MAN/ITEM TASKS	YES	NO	N/A	COMMENTS

YES = Adequate NO = Inadequate N/A = Not Applicable

- Operating elements, etc.

for HFE considerations such as: location and arrangement, sizes and shapes, directions and forces required to operate, clearances, visibility, environment and use conditions, safety and operational conditions. They also contain detailed guidance on the method of checklist application, data reduction and data analysis.

Task checklists (example in Table 11) are used to evaluate operator/maintainer task performance while the operator is engaged in job performance. The checklist itself is simply a sequential listing of tasks to be performed, with space available on the form to check (1) adequate task performance, (2) inadequate task performance, or (3) task not performed. For tasks that have been inadequately performed, the evaluator can make comments concerning potential problem areas which may contribute to that performance. The checklist itself is relatively simple to construct, but application requires both a moderate to high level of HFE experience and an understanding of the equipment. Further, tasks may proceed at a rate faster than an evaluator may be able to monitor performance, respond to the checklist, and make notes regarding task performance and operator comments. Videotape recordings (such as those proposed in Task Analysis Reduction Technique (TART)) can be of great utility in applying task checklists.

Error Analysis

Error Analysis techniques are used in performing trade-offs or identifying areas where redesign of equipment or procedures is required. The purposes of error analysis are to identify areas where design concepts may tend to reduce operator reliability in critical functional areas. Three analyses are of particular interest, the Task Analysis approach, the OSD approach and Equipment Error Probability Analyses (Malone, 1976).

The Task Analysis and OSD approaches address procedural errors and potential consequences. The procedure entails examining each task, function or activity in order to identify potential errors. For each potential error identified, assessments are made concerning:

- Impact of error occurrence on system or mission failure probabilities
- Operator safety as a result of error occurrence
- Degree to which equipment design can have positive influence, error likelihood and/or mission reliability
- Degree to which procedural design can reduce error occurrences and enhance mission reliability

Assessments of equipment error probabilities are made for controls and displays according to estimations of error types.

Control errors are described as being:

- Inadvertant actuation
- Substitute - incorrect selection of a control
- Activation - incorrect setting
- Temporal - control activator at incorrect time
- Sequential - operating control out of sequence
- Omission - failure to operate a control

Display errors include:

- Reading - misreading a display
- Substitution - reading the wrong display
- Interpretation - correctly reading but misjudging the displayed information
- Omission - failure to receive the displayed information

Judgments are required to estimate probability of each error dimension for each control or display according to (1) high probability of error, (2) moderate probability, or (3) low probability of error. Error criticality estimates are also made and are estimated to be high, moderate or low criticality.

Controls and displays that are of high or moderate criticality and which have moderate or high probability of error occurence on any dimension are considered as requiring both additional evaluation and redesign. An example of error likelihood analysis format is shown in Figure 24 for controls and Figure 25 for displays.

Functional Description Inventory

Helm (1976) has described the Functional Description Inventory (FDI) as a tool to quantifiably assess the effectiveness of man/machine interfaces. The procedure requires the analysis of the operational functions of each crewmember. The functions are hierarchically determined by roles, duties and tasks performed by each operator. Operator judgments for roles, duties and tasks are selected to determine average crewmember judgments towards:

- Importance for mission success
- Frequency of performance
- Training adequacy
- System effectiveness

For each role, duty and task, crewmembers are requested to respond to each of the four items above on a scale of five.

CONTROL ERROR LIKELIHOOD WORKSHEET

Test Item __________ Test Title __________

Console __________ Test Project No. __________ Date __________

Control Name	Errors*					Error Criticality			
	Inadvertent Actuation	Substitution	Activation	Temporal	Overall Rating	Likelihood of Detection - Correction*	Magnitude of Error Effect	Criticality Rating*	Comments

*Ratings: 3 - High, 2 - Moderate, 1 - Low

FIGURE 24

DISPLAY ERROR LIKELIHOOD WORKSHEET

Test Item ______________ Test Title ______________

Console/Panel ______________ Test Project No. ______________ Date ______________

Display Name	Errors*					Error Criticality			
	Substitution	Reading	Intepretation	Temporal	Overall Rating	Likelihood of Detection*	Magnitude of Error Effect	Criticality Rating*	Comments

*Ratings: 3 - High, 2 - Moderate, 1 - Low

FIGURE 25

Data are analyzed by:

- Rank ordering responses (importance, frequency, training effectiveness and system effectiveness) for roles, duties and tasks
- Computing frequency distribution
- Computing mean and standard deviations of responses for individual roles, duties and tasks

Further, standard scores can be compounded (criticality and frequency of use, for example) reflecting the combined weights of the duties rated in these parameters.

Development of the technique was continued by O'Conner (1977) who termed it a Decision Analytic Technique (Figure 26). A rating scale was developed (after role duty, task hierarchy development) emphasizing workload and system effectiveness. Pilots (F-18 aircraft) rated both tasks along the workload dimensions and system effectiveness. A paired comparison technique was used to weight task criticality. Both FD1 and Design Analytic Technique are part of the Mission Operability Assessment Technique (MOAT) being developed at the Pacific Missile Test Center.

T&E Kits

HFE Kits and a variety of measurement tools are available to aid in HFE T&E. One particular kit which has been assembled by Perceptronics includes the following:

- Sound level meter and analyzer
- Vibration meter and analyzer
- Photometer
- Spot brightness meter
- Force/torque and dimension kit
- Portable weather station (with readouts that can be located away from the actual measuring devices. Readouts indoors, for example, while the weather station is out-of-doors)
- Hot wire anemometer
- Aspirating Psychrometer
- Thermometer (digital)
- Gas tester (universal)
- Monitoring gas sampler
- Anthropometry instrument kit (goniometers, tapes, etc.)
- Digital time
- Event counter (multiple)
- Camera (Polaroid SX-70)
- Video recording system

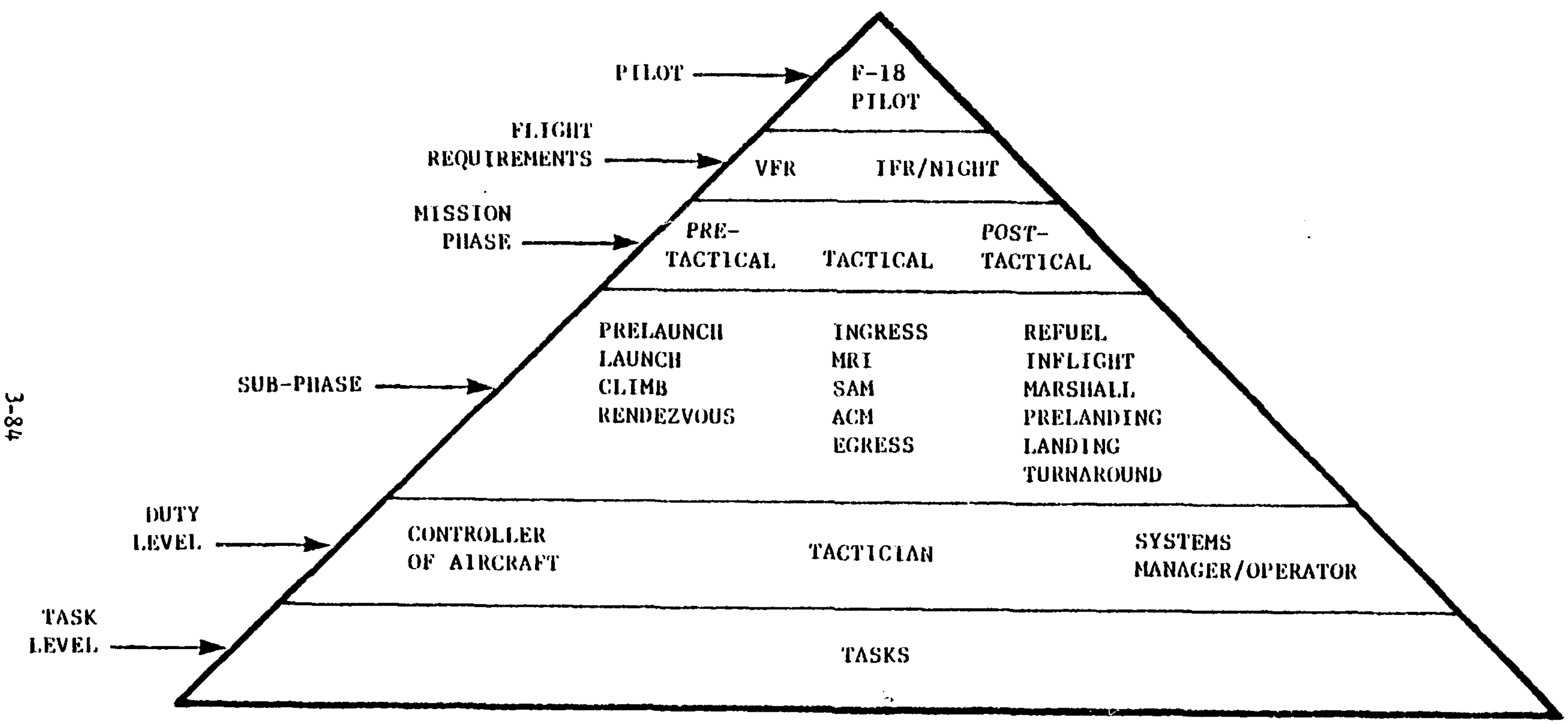


FIGURE 26
F18 PILOT TASK INVENTORY HIERARCHY

(From O'CONNOR, 1977)

- Audio tape recorder
- Instrumentation tape recorder
- Scientific calculator
- Digital test meter
- Tool kit
- Battery charger

Additional tools that may comprise an HFE kit are film editors, surface pyrometers (for roughly 100°F plus surface temperatures), anthropometric positioners, movie cameras, projectors, screens, portable radio systems, tripods, etc.

Many of the individual tools of an HFE kit are used during actual operations and hence a goal is to select tools that are as unobstrusive as possible, so as not to effect operations and potentially corrupt the data.

TART

The Task Analysis Reduction Technique (TART) (Ellis, 1970) serves as an aid to evaluating workstation designs using either mockups or real equipment. The purpose of TART is to minimize loss when quantifying performance and to improve the usability of the qualitative form of the data; that is, to increase the identity between actual task performance and data that describe it.

The tool employs a video recording system for data collection, a video playback device and Task Analysis - Operational Sequence diagrams for analysis. The actual steps in TART application are as follows:

- Develop TA/OSDs
- Video tape task performance (using mockups or actual equipment)
- Establish a timeline using video playback
- Analyze a timeline to determine:
  - task frequency
  - task loading
  - sequential task impulses

PAARS

Personnel Activity Analysis Radio System (PAARS) (Potema, 1969) is a field testing technique to collect job activity information and data via a radio system. Radios are used in the technique by one (or more) HF analyst during operator task performance. As applied, operator activities at various workstations can be timed, phased, sequenced and task checklists can be applied. PAARS allows tape recordings to be made during

operations. The technique requires a base station and a supply of walkie talkie type radios. These can be either used by actual operators or HF analysts. Application requires that an operator (or observer) vocalize tasks during performance. PAARS may be valuable in generating or verifying OSDs, establishing timelines.

Human Reliability

A technique for the Allocation of Man-Machine Reliability is described in the Human Reliabilitiy Prediction System Users Manual (1977). The purpose of the technique is to permit equipment and human operator/maintainer (reliability) to be addressed as part of design trades. The basic concept is Operational Reliability, of which the human operator is viewed as an integral part.

Steps in applying the technique are: (1) to identify critical functions and reliability and maintainability design parameters (in effect, construct a function probability tree), (2) identify constraints to allocations for:

- Minimum mission reliabilities
- Minimum operational readiness
- Maximum cost (life cycle, acquisition, support)
- Personnel (number, skill level requirements) and

(3) maximize the equation:

Operational Reliability = $(P_i \cdot r_i)$; where
P_i = probability of a mission, and
r_i = mission reliability.

The technique is stated to have application to performance of maintenance or operability trade-offs, e.g., the essential tradeoffs on: (1) automation and human maintenance reliability, versus (2) manual system and human operational reliability, versus (3) equipment reliability of various levels of automation. A simplified dynamic programming procedure for maximizing the equation is given and provided in Figure 27.

A technique for predicting the probability of maintenance task success is compounding (Human Reliability Prediction Systems Users Manual, 1977). Three steps are involved in applying the technique:

1. Multidimensional scaling
2. Individual performance index computations
3. Reliability index computation

Multidimensional scaling involves the identification of tasks involved in system maintenance activities. A factor analysis was performed and general job factors emerge.

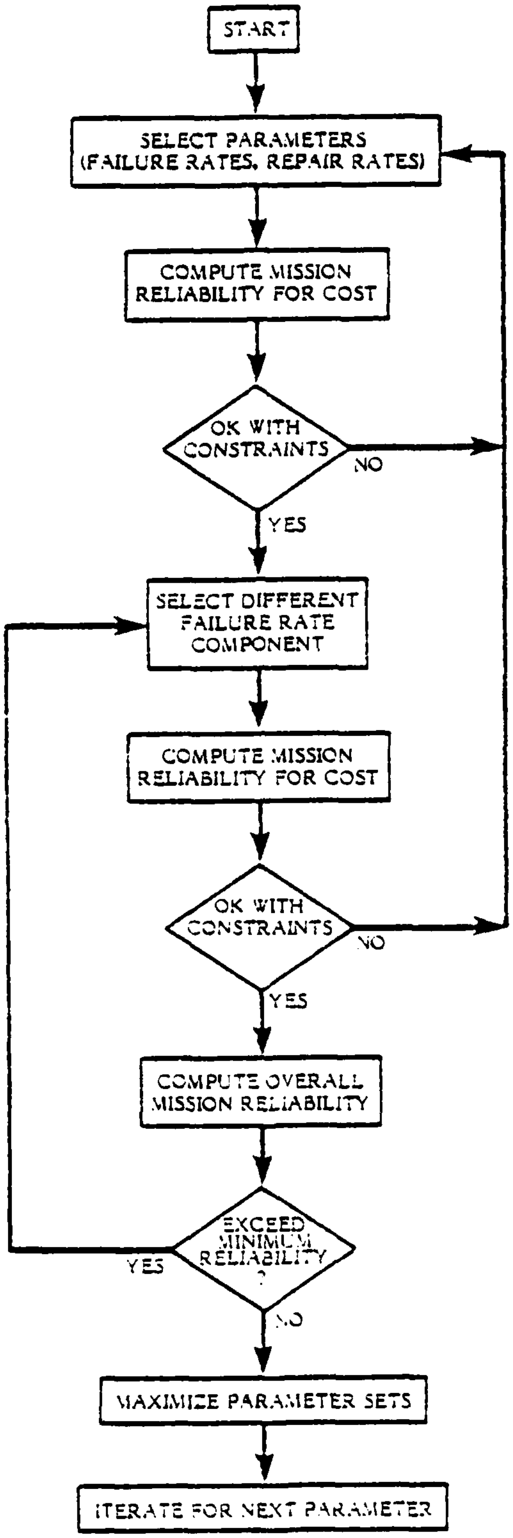


FIGURE 27
PROCEDURE FOR FUNCTIONAL ALLOCATION BASED ON
RELIABILITY ESTIMATES AND RELATIVE COSTS

A factors analysis for electronics systems is performed and factors (said to be applicable to all electronic system maintenance activities) are reported as being electro-cognitive, electro-repair, etc. Once job factors are identified, personnel performance index (PPI) computations are derived according to tasks in the scaling (factors). This entails identifying usually effective (UE) and usually ineffective (UI) maintainer performance on a series of task performances. The performance index is then calculated by the following formula:

$$PI = \frac{UE}{UE + UI}$$

which is simply the ratio of successful performances over total rated observations. With the availability of performance indices for each maintainer for each factor, human reliabilities for individual malfunctions of a system can be estimated by computation. Formulas for estimating human reliability are provided for:

- Series Maintenance Activities - simply determine product of performance indices
- Parallel Maintenance Activities - where two or more maintainers perform independently
- Complex Maintenance Activities - where task dependency exists between two or more maintenance technicians

The data to apply the technique to electronic systems are in Table 12 and these data are said to be applicable to any such system. For other systems, multidimensional scaling will have to be performed in order to apply the technique (e.g., hydro-repair, hydro-safety, etc.). Data to perform the factor analysis, as well as the determination of PPIs, is reported as being provided by judgments of experienced personnel and presumably the same or a similar method could be undertaken for hydraulic or mechanical systems.

MIL-HDBK-472, Maintainability Prediction (1966) provides four procedures for estimating system maintainability. The procedures each address one of four separate maintainability issues, as follows:

Procedure 1:	Predicts system downtime of airborne electronic and electromechanical system involving model replacement of components.
Procedure 2:	Predicts corrective, preventive and active maintenance parameters (specifically maintenance time)
Procedure 3:	Predicts maintainability of ground electronic systems and equipments (mean downtime)
Procedure 4:	Predicts system downtime as a function of system history and subjective judgments

TABLE 12

PERSONNEL PERFORMANCE INDEXES
(HUMAN RELIABILITY PREDICTION SYSTEM USER'S MANUAL, 1977)

Job Activity	Career Field (Navy)							
	EM	ET	FT	IC	RD	RM	ST	TM
Electro Cognition	.55	.83	.86	.62	.33	.63	.92	.36
Electro Repair	.78	.99	.92	.70	.30	.71	.70	.40
Instruction	.75	.95	.97	.45	.57	.95	.51	.66
Electro Safety	.60	.98	.95	.65	.92	.70	.42	.62
Personnel Relationships	.74	.70	.79	.63	.40	.77	.85	.80
Electro Circuit Analysis	.63	.90	.95	.58	.40	.65	.74	.60
Equipment Operation	.92	.85	.95	.65	.90	.85	.92	.75
Using Reference Material	.73	.90	.87	.62	.95	.92	.88	.66

EM - Electrician's Mate
ET - Electronics Technician
FT - Fire Control Technician
IC - Interior Communications Electrician
RD - Radarman
RM - Radioman
ST - Sonar Technician
TM - Torpedoman's Mate

Table 13 provides basic information for each procedure concerning its application, measures, inputs and reliability.

ERUPT

Two techniques have been reported by Beek (1967): (1) ERUPT (Elementary Reliability Unit Parameter Technique) and (2) Multiple Correlation Approach to the identification of personnel characteristics which show greatest effects of system failure and repair rates.

ERUPT is a technique for the estimation of two total system readiness parameters:

1. Probability that a failure is detected and repaired
2. Probability that maintenance does not induce failures

In ERUPT, systems components are grouped into ERUs (Elementary Reliability Units), which become the units by which reliability of the total system is estimated. Each ERU has a reliability which is estimated from: probability of failure; probability of storage failure; probability of repair (while in storage or in operation); and a probability of failures induced during maintenance. Total system reliability is considered to be the product of ERU reliabilities.

The process of applying ERUPT is essentially a working backwards from observed component (ERU) reliability to estimates of human reliability; that is, human reliability (probability of malfunction detection and correction, probability of malfunctions induced during maintenance) is derived by inference between actual (shipboard ERU reliabilities) and inherent (test) reliabilities.

The Multiple Correlation Approach to maintenance personnel selection is similar to ERUPT in that it uses operational and test data, from already existing systems and/or components. The method employs data (from Navy files concerning equipment failure, e.g., number of repair actions required per unit time and MTTR) and characteristics of technicians performing the maintenance (age, pay grade, experience, time left in service, education rating and training time). Correlations are performed using personnel characteristics predictions and equipment failure data as criteria. Multiple correlations are performed and interrelationships between the variables are assessed. Results of the analysis may be used to identify personnel requirements which significantly influence system reliability (in terms of human reliability and MTTR).

Another technique reported in the Human Reliability Prediction Systems User Manual (1977) is Flow Chart (FC) Maintainability (M) Prediction. This technique is one

Procedure	Applicability	Point of Application	Basic Parameters of Measure	Information Required	Correlation	Caution
I	To predict flight line maintenance of airborne electronic and electromechanical systems involving modular replacement.	After establishment of the design concept provided that data as listed in the column entitle "Information Required" is available.	Distribution of downtimes for various Elemental Activities, Maintenance categories, Repair times, and System Downtime.	(a) Location & failure rate of components (b) Number of: 1. Replaceable components 2. Readouts 3. Spares 4. Test Points 5. Magnetrons (c) Duration of Average mission (d) Maintenance schedules, etc.	See Figure 1-1 to 1-6 for correlation between the observed and predicted values of various maintainability parameters.	It may be necessary to identify additional elemental activities and derive their appropriate parameters for application to equipments other than those indicated under Applicability.
II	To predict the maintainability of shipboard and shore electronic equipment and systems. It can also be used to predict the maintainability of mechanical systems, items provided that required task times and functional levels can be established.	Applicable during the final design stage	Part A of procedure: Corrective maintenance expressed as an arithmetic or geometric mean time to repair in hours. Part B of procedure: Active maintenance in terms of: (a) Mean corrective maintenance time in manhours. (b) Mean preventive maintenance time in manhours. (c) Mean active maintenance time in terms of mean manhours per maintenance action.	For corrective maintenance (Part A): (a) packaging: to the extent that detailed hardware configurations can be established. (b) Diagnostic procedures. (c) Repair methods. (d) Parts listing. (e) Operating stresses (f) Mounting methods (g) Functional levels at which alignment and checkout occur. For active maintenance (Part B): The respective maintenance task times for corrective and preventive maintenance must have been determined.	A validation study of the AN/URC-32 Transceiver and the AN/SRT-16 Transmitter, which were used on many ship types from destroyers to submarines, showed good correlation between predicted and observed corrective maintenance results.	The tabulated task times are not applicable to all types of equipments and situations. For a particular application, when the validity of the task times is in question, addition data sources may have to be used or estimates made by the analyst.
III	To predict the mean and maximum active corrective maintenance downtime for ground electronic systems and equipment. It may also be used to predict preventive time.	Applied during the Design Development and Control Stages	(a) Mean and maximum active corrective downtime (95th percentile) (b) Mean and maximum preventive downtime (c) Mean downtime equipment (e) Maintenance aids (f) Operational and Maintenance environment	The evaluator must have accessibility to be familiar with at least the following: (a) Schematic diagrams (b) Physical layouts (c) Functional operations (d) Tools and test tasks to be evaluated	Correlation between dicted and observed values can be good if: (a) Adequate information is available (b) Experienced analysts are used to select maintenance	The scoring of the respective checklists must be performed by analysts who are well familiar with the equipment. It is reasonable to expect variation in the regression coefficients as maintenance situations and equipments change. The extent of this variation has not as yet been determined.
IV	To predict the mean and/or total corrective and preventive maintenance downtime of systems and equipments.	Applicable throughout the design, development cycle with various degrees of detail.	(a) Mean system maintenance downtime (b) Mean corrective maintenance downtime per operational period. (c) Total corrective maintenance down-	Complete system documentation portraying: (a) Functional diagrams (b) Physical layouts (c) Front panel layouts (d) End item listings with failure rates.	Among similar procedures correlation between predicted and observed values has been good.	Care must be exercised in the estimation of times where data is not available. Sufficient equipment disclosure must be available to establish reasonable estimates.

TABLE 13
SUMMARY OF MIL HDBK 472 PROCEDURES (from MK HDBK 472)

which emphasizes troubleshooting of electronic circuits, and its purposes are to estimate maintenance times for circuits, to help standardize troubleshooting procedures, and to aid in identifying required numbers of maintenance steps through the establishment of troubleshooting priorities.

The steps required to apply the technique are as follows:

- Conduct a Level of Repair (LOR) analysis
- Conduct a Failure Modes Effects Analysis (FMEA) to determine symptoms resulting from component failures
- Evaluate the results of steps one and two above, and develop a troubleshooting flow diagram

The diagram should indicate logic (from step two, above) and repair actions that may be required (from step one, above). The diagram should be developed with a view to (1) employing half-split troubleshooting techniques (roughly half of a circuit is diagnosed as faulty or not at each test point) and (2) emphasizing that troubleshooting actions stem from logical deductions (control panel indicators, symptoms, etc.). The final step in the technique is to:

- Determine or estimate, for each flow chart step (logic or maintenance action)
    - test equipment setup time
    - overall system diagnosis time
    - modular isolation/localization time (troubleshooting to malfunctioning component time)
    - module removal time (for replaceable components)
    - module installation and checkout time

Data sources are quoted as tables in MIL HDBK 472 (maintainability prediction) and maintainability engineers judgments. Formulas are provided to determine MTTR (Mean Times to Repair) using the data from MIL HDBK 472 data.

MONTE

Another technique that samples end points of decision and probability stress is called Step Through Simulation (Ulvila, 1977) (Figure 28), which uses a computer program called MONTE (short for Monte Carlo Simulator). Basically, MONTE uses random sampling techniques for estimating outcomes through samples of paths through a tree network, yielding a probability distribution of all possible outcomes. A decision maker interacts with MONTE via a CRT and light pen. The program poses questions and appropriate data to the decision maker. After having examined the data provided, the decision is entered (e.g., engage target). The random sampler selects an outcome (based on some input probabilities) for events subsequent to the decision (target destroyed,

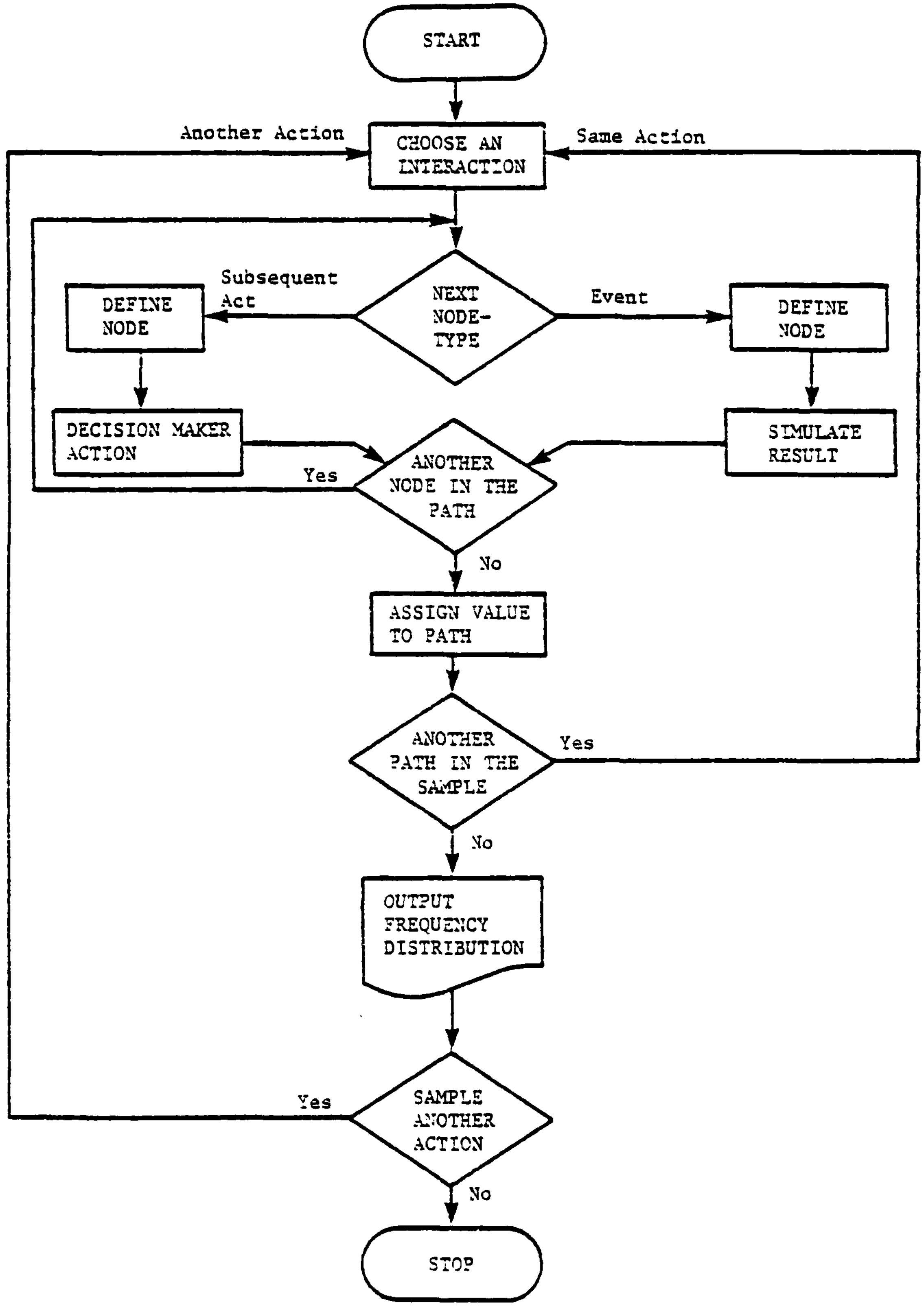


FIGURE 28
PROCESS DIAGRAM OF STEP-THROUGH SIMULATION

target missed, damage sustained, etc.). Based on the outcome, another decision is requested (resume engagement, return to base), and the process is continued until the mission (for that trial) has been successfully or unsuccessfully completed. The process is iterated several times until sufficient data are available to establish an outcome distribution.

In order to use MONTE it is necessary to construct a tree network that shows points where decisions are to be made, and for each option provided in a decision, estimations of outcomes to a subsequent decision. These data need then to be entered into the program for execution.

Outputs of MONTE include frequency distributions of mission successes and failures and decisions made at various points. MONTE could be a valuable tool in JPA trade-offs, JPA design, identification of learning objectives, etc.

Job Performance Aids

Although job performance aids (JPA) or "performance aiding technology" had a definitely slow and meager period, the technology is being rediscovered. Previous dissatisfaction with development, narrowness of research and ineffective implementation has been overcome by the need for more effective methods of using the level of manpower engendered by the all-volunteer military. JPAs are considered one way to enhance human performance in system operation and maintenance.

A performance aid is defined as that which stores information for later retrieval in connection with the performance of a job (Joyce, 1975). It facilitates performance by reducing memory requirements imposed on the user. Examples include checklists, schematics, assembled procedures, books of tables, nomograms and technical manuals. The JPA is not a substitute for training, its basic function should be to supplement and support training, with JPA materials being used in actual training (Malone, et al, 1974). Their basic function is to reduce maintenance costs, increase equipment usability, assure the need for less training and less skilled personnel. The use of JPA significantly reduces maintenance costs and training time.

The basic decision as to the trade-off between training and use of JPAs is operator performance as well as savings in terms of cost and time. Table 14, adapted from the Air Force Systems Command DH 1-3 Handbook on Human Engineering, lists the factors to be considered in the decision as to training vs. JPAs. Post (1977) developed the "warrants concept" to make selection of formats and media systematic, match cost and formats to needs, justify costs in terms of maintenance or personnel benefits, improve level of TM

TABLE 14

TRAINING/JPA DECISION CRITERIA
(AFSC DH 1-3)

Factors in Decision

a. Ease of learning
b. Ease of communication by book
c. Task criticality
d. Task difficulty (how prone to inadequate performance)
e. Importance of reaction time or response rate
f. Frequency of task performance
g. Number of similar tasks
h. Psychomoter skill component of task
i. Rate of stimulus input
j. Rate of response output
k. Equipment complexity
l. Rate of stimulus input
m. Environmental considerations
n. Mission criticality
o. Consequences of improper step performance on task performance
p. Personnel hazards
q. Audience career orientation
r. Number of individuals who perform a task

Put in Training

a. Tasks that are not very easy to learn on-the-job
b. Tasks that are hard to communicate with words
c. Tasks that need a great deal of practice for acceptable performance to be established
d. Tasks where there is little room for error
e. Tasks where consequences of error are serious
f. Tasks that do not take exorbitant sums of money to train
g. Tasks which are performed frequently on-the-job
h. Tasks in which the required speed or response rate does not permit referring to a manual
i. Tasks performed by a large proportion of the individuals in a given specialty

Put in Job Performance Aids

a. Behavior sequences that are long and complex
b. Tasks that are rarely performed
c. Tasks that involve readings and tolerances
d. Tasks that can be mentally rehearsed before the need to perform them arises
e. Tasks that are aided by the presence of illustrations
f. Tasks that utilize reference information such as tables, graphs, flow charts and schematics
g. Tasks with branching step structures

usage and arrive at a mix of aid forms in consideration of tasks, maintenance and personnel conditions. This approach uses, for example, the maintenance technical data presentation and user directive aids such as Fully Proceduralized Job Performance Aids (FPJPA) maintenance action procedures in a technical manual, deductive aids such as MDCs, or functional flow diagnosis. This approach is of most use in troubleshooting situations. Post (1977) also suggests that the aid have two features: (1) ability to be revised by user feedback or conform with changes in the systems and (2) progress with personnel advances. This would allow the user to progress from a purely directive aid (with complete troubleshooting procedures, spelling each step out) to a deductive aid in which the user selects the test sequence which would permit him to deduce the cause of a problem. The deductive aid creates in the user a sense of accomplishment; however, the personnel organization must recognize this need for encouragement of the user's desire for further advancement. Post and Price (1976) point out that the job satisfaction criteria must be considered, i.e., opportunity to learn the meaningfulness of the work and challenge. The directive aid excels in this criteria, especially for experienced technicians. To satisfy this situation, the hybrid Augmented Action Tree Troubleshooting Aid (JPA AATTA) was developed which allows novice technicians to conduct troubleshooting while at the same time giving the more experienced technicians the opportunity to learn career-relevant skills.

With the decision made as to the use of JPAs, various JPAs presently conceived can be utilized or a specific JPA developed. One of the most comprehensive discussions of JPA development is the Air Force Human Engineering Handbook DH 1-3. This document defines specific step-by-step procedures for design of JPAs.

Booher (1977) has organized a model assuming three major levels for JPA technology; (1) the JPA system level, (2) the performance aid component level, and (3) the performance aiding element level. The system is comprised of several types of formats for different categories of behavioral tasks (lubricate, remove, fault, isolate, etc.); the formats can entail tables, lists, functional blocks, matrices, etc. Use of a task analysis or special training requirements are decided at this step. These performance aids lead to the presentation concept. The different features of a presentation component will aid a specific behavior, i.e., reading voltages, reading wave forms. The third level, performance aiding element level, entails decisions as to readability and personnel factors.

One available technique for evaluating JPAs is that of Ayoub, et al (1976). The technique presents a computerized approach for developing specific rules and guidelines for developing and producing JPAs. A computerized model of the maintenance system

allows evaluation of the effects of different management policies or maintenance tasks and enables performance of cost-benefit analysis of design alternations and approaches. It also allows experimentation with different JPA alternatives without the need for field investigations.

FOMM

Roader and Ranc (1975) state that the Functionally Oriented Maintenance Manual (FOMM): (1) decreased maintenance workload by improving the accuracy of maintenance actions; and (2) reduced costs associated with maintenance training, i.e., textual materials. The production of such materials involves understanding of system operations, as well as selecting formats readily understood by the user. Neither of these functions are amenable to computer applications. Shriver (1977) states that there is a definite trend toward automated troubleshooting. This trend is based on the realization that the troubleshooting situation is not a problem-solving situation but is rather an operation which can be fully proceduralized. There is, therefore, a good deal of attention being directed toward the formal and informal, due to the lower skill levels required in using FOMM data. FOMM was also found, however, to cost 40 percent higher than conventional methods.

TREES

A computerized method to provide maintenance technicians with technical data is TREES (Tree Structured Data). TREES also provides for modifications to maintenance data and provides taily proceduralized guidance through system checkout and repair activities (Colwell, 1971).

The method employs a computer program, terminal and keyboard interacting with five subprograms; Build (tree construction), Loads (inputs interaction commands and statements), Edit and Bump (data base maintenance), and Query. The Query subroutine represents the interaction of the maintenance technician in the course of maintenance activities. The program provides data and instructions to the maintenance technician, and after the instructions have been completed, the technician responds to questions posed by the subroutine (multiple choice, yes or no responses). Based on the response input by the technician, a path along the tree is selected and the process is iterated until troubleshooting, checkout or repair is completed.

Instructional Systems Development

Instructional Systems Development (ISD) is a methodology for managing training system design and development. ISD divides training system development into distinct

phases with steps and objectives to accomplish within each (Funaro, 1978). An ISD model of particular interest is the Interservice Procedures for Instructional Systems Development (IPISD), reported by Logan (1977). IPISD model is divided into five phases:

1. Analysis
2. Design
3. Development
4. Implementation
5. Control

Activities and outputs for each of these phases are presented in Table 15. As a management tool, IPISD structures training system development according to the phase activities outlined in the table. Analytic and design techniques used to accomplish the objectives of each step are more or less free to vary according to such considerations as system size and complexity, whether or not the training system is for an existing or a new weapon system, whether the training system is designed towards system operation, maintenance or both and so on.

Training Requirements Analysis

Training Requirements Analyses is a tool that identifies required skills and knowledges of system operators and maintainers. Job tasks, training tasks, performance standards, and central skills are identified for each position. The analysis is basically an examination of position description, task analysis, JPA requirements, and ILS (LOR, for example) data, and the appropriate skill and knowledge requirements are identified.

Job Analysis

Job Analysis is a method for identifying and analyzing training requirements from data available in systems similar to the developing system. Like Training Requirements Analysis, Job Analysis identifies and catalogs job tasks according to function and skill and knowledge requirements and, as its primary purpose, aids in identifying training objectives and provides input to training system trade-offs (JPA, media selection, personnel requirements, etc.).

Training Media Selection

Training media selection represents a central and difficult step in a training system development process. Learning objectives must be matched to media types and methods, within such constraints as cost, training time and manpower availability.

TABLE 15
PHASE ACTIVITIES AND OUTPUTS FOR THE IPISD MODEL
(LOGAN, 1977)

Phase	Activities	Outputs
Analyze	• Job analyses • Task function selection • Select job performance measures • Analyze existing courses	- Job task list - Training task list - Job performance measures - Instructional setting selection
Design	• Develop learning objectives • Develop tests • Describe entry behaviors of students • Develop task learning structure	- Learning objectives and analyses of each task - Test items selected - Entry behavior test - Dependent task sequences
Develop	• Learning events/activities specification • Plan instruction management • Select materials • Develop instructions • Instruction validation	- Learning objective taxonomies - Learning materials - Instructions for all learning objectives - Tested and revised instructional materials
Implement	• Apply instructional management plan • Conduct instruction	- Required management documents and tools - Implementation of training system
Control	• Conduct internal/external evaluation • Analyze and revise system	- Instructional effectiveness data - Field job performance data - Instructional system revision.

A technique known as Means to Achieve Performance (MAP) (Tannebaum, 1976) was developed to aid in performing trade-offs between (1) personnel selection, (2) training, (3) performance aids and (4) reference documents in order to optimize human performance.

Application of MAP employs a checklist showing pertinent tasks and activities and each of the options stated above. Tasks are assigned to an option (or phase) according to guidelines provided in Table 16.

A technique for selecting cost-effective instructional media, TECEP (Training Effectiveness, Cost Effectiveness, Prediction Techniques), has been developed by the Training Analysis and Evaluation Group at the Naval Training Equipment Center (Braby, Henry, and Morris, 1974). The purpose of TECEP is to aid in choosing cost-effective instructional media for training systems.

The technique is applied in nine steps which organize training objectives into groups; potential learning strategies for each group are defined, appropriate media are selected and cost trade-offs are performed. The specific steps are as follows:

1. Classify training objectives according to the sixteen categories provided (continuous movement, decision-making, voice monitoring, etc.).
2. For each category, define a learning strategy. A summary table of learning guidelines for each category is provided; for example, learning guidelines for decision-making tasks include:
   - access to relevant data provided to trainees
   - overlearning of skill required to help overcome effects of stress, etc.
3. Identify media characteristics which match learning strategy and objectives. The report provides general training media characteristics according to five classes:
   - stimulus capabilities
   - trainee response modes
   - information feedback logic
   - event sequence logic, and
   - instructional setting
4. Select media that contain the characteristics identified in step three. A table of media classes is provided (and presented in Table 17).
5. Reject inappropriate or impractical media approaches according to considerations such as:
   - state-of-the-art of the medium
   - system size and inherent medium practicality
   - time requirements
6. For each remaining media, estimate time to achieve objectives.
7. Propose alternate training systems for trade-offs.
8. Estimate cost (annual) for each training system.
9. Select optimum training media mode.

TABLE 16
GUIDELINES FOR SELECTION OF MEANS TO ACHIEVE PERFORMANCE

(from Tannenbaum, 1976)

PERSONNEL SELECTION may be an option when:

1. Availabe Bell System people have the required skills and knowledge.
2. Skills and knowledge are complex, and training, references or performance aids are costly to develop and maintain.
3. Not many people are required to perform this activity.
4. Rapid start-up time is required.

TRAINING may be an option when:

1. Speed and/or accuracy levels must be demonstrated before starting on the job.
2. On-the-job speed is so critical that there is not time to use a performance aid or a reference document.
3. A period of familiarization is needed before starting work.
4. Activities may be too complex to learn without instructions.
5. Skills and knowledge required are system specific.
6. Performance aids and/or references need practice, demonstration, or explanation before use on-the-job.
7. Large numbers of performers
8. Training modules exist for this activity.

Continued

9. It is more cost effective to train a lower paid person than to select existing personnel.
10. Skills and knowledges need to be enhanced.

PERFORMANCE AIDS may be an option when:

1. Speed and/or accuracy must be assured at the time of performance.
2. Procedures or sequences are required and memory needs to be supplemented or substituted.
3. Assistance is needed to make decisions and/or judgments.
4. The speed of finding, retrieving, or using information needs to be increased.
5. Activities are considered to be complex.
6. Activities are performed infrequently.
7. Conversion of information is required.
8. Quantity of information is too great to remember.

REFERENCE DOCUMENTS may be an option when:

1. Activities are performed infrequently; retention of information is not likely.

TABLE 16
(Continued)

REFERENCE DOCUMENTS may be an option when:

2. Decision-making guidance is required; the worker will need information ordinarily presented in handbooks, extensive formula tables, computer programs, and the like, rather than performance aids.

3. A full description of the work is required, possibly including background or perspective, in order to plan or to carry out the instructions.

4. Visual reinforcement for procedures, such as that provided by illustrations, or other graphics, is required.

5. Cross-referencing is required, such as matching information from one complicated source with information from another similar source.

TABLE 17
MEDIA CLASSES
(from Braby, Henry and Morris, 1974)

Audio Disc Playback System	Teaching Machine, Branching, Still and Motion Visual with Audio
Audio Tape System	Teaching Machine, Linear, Still and Motion Visual with Audio
Dial Access Information Retrieval System - Random Audio	Teleconference System
Dial Access Information Retrieval System - Scheduled Audio	Television - Cable (CATV)
Language Laboratory - Audio, Active - Compare Mode	Television - Cartridge (CTV)
Language Laboratory - Audio Passive Mode	Television - CCTV with Feedback
Physiological Trainer (Hostile Environment) Auditory	Television - Closed Circuit (CCTV) without Feedback
Radio System - AM/FM	Television - Open Broadcast
Radio System with Responders	Television - Portable Video Tape System
Telephone Conference System	Television - Video Disc System
Carrel, AV Equipped	Carrel, Laboratory
Computer Assisted Instruction (CAI)	Computer Assisted Instruction: IBM Aids with Adjunct Equipment
Computer Assisted Instruction: IBM Aids	Computer Assisted Instruction: Plato IV, Basic Configuration with Adjunct Equipment
Computer Assisted Instruction: Plato IV Basic Configuration and Audio	Computer Assisted Instruction: Plato IV Basic Configuration with Adjunct Equipment and Audio
Dial Access Information Retrieval System Scheduled Audio/Video	Filmstrip Projection System with Audio and Adjunct Equipment
Filmstrip Projection System with Audio	Operational Equipment with Manuals
Game, Manual Non-Simulation	Operational System - Real Environment
Game, Manual Simulation	Operational System - Synthetically Simulated
Motion Picture Projection System - Commercial, 16MM and Super 8MM Films	Operational System - Synthetically Stimulated
Motion Picture Projection System - Low Budget 16MM and Super 8MM Films	Procedure Trainer
Student Response System: AV Supported	

TABLE 17
(Continued)

Procedure Trainer - Adjunct Displays and Logics

Simulator

Simulator - Adjunct Displays and Logics

Teaching Machine - Branching, with Adjunct Equipment

Television - Video Disc with Adjunct Equipment

Audio Tape with Printed Material

Classroom - Traditional

Microfilm with Information Mapping and Audio

Multi-Media Kits with Instructor

Overhead Projection System with Instructor

Sound Slide Projection System

Teaching Machine - Branching, Still Visual with Audio

Teaching Machine - Linear, Still Visual with Audio

Multi-Media Kits for Trainees

Sound Slide Projection System with Adjunct Equipment

Game - Computer Supported Simulation

Models and Static Mockups - Small Scale

Physiological Trainer (Hostile Environment) Visual

Computer Assisted Instruction: Plato IV Basic Configuration

Filmstrip Projection System

Logic Trainers

Microform with Information Mapping and Adjunct Equipment

Mockups, Panels, and Demonstrators - Dynamic

Programmed Text - Branching with Adjunct Material/Equipment

Automatic Raters - Informal Training

Carrel - Dry

Case Study Folder

Flash Cards

Microform with Information Mapping

Printed Materials - Handouts

Printed Materials - Performance Aids

Printed Materials - Reference Books

Printed Materials - Reference Charts

Printed Materials - Self Scoring Exercises

Printed Material - Textbook

Printed Material - Workbook

Programmed Text - Branching

Programmed Text - Linear

Simulation - Paper

Slide Projector System - 2" x 2"

Study Card Sets

Teaching Machine - Branching, Still Visual

Teaching Machine - Linear, Still, Visual

Do-It-Yourself Kits

TABLE 17
(Continued)

Mockups, Panels and Demonstrators - Static

Specimen Sets

Computer Simulation - Off-Line

Computer Simulation - On-Line

Game - Computer Simulation - Solitaire - with Visual Display

Physiological Trainer (Hostile Environment) Surface and Internal Senses

Campbell and Hughes (1978) have developed an 11-step process to help determine media requirements for each learning objective and to optimize mixes of media applicable to those requirements. The 11 steps of the technique (see Figure 29) are devoted to determining and analyzing (1) study session and (2) training device media alternatives. The 11 steps are as follows:

1. Identify learning objectives as being study type (classroom, i.e.) or training device type (maintenance trainers, etc.) objectives
2. Design study session objectives as applicable to, or requiring example sets (troubleshooting input, etc.), or not requiring examples (fixed procedures for example)
3. Identify special requirements for study session objectives. Examples include color, cues, instructor evaluation, etc.
4. List acceptable media for each study session objective. The others provide a matrix with special characteristics listed in the column and media types along the row (CAI, lecture and slides, etc.), and appropriate media are identified for special characteristics.
5. Rank applicable media according to estimated cost, present media availability, etc.
6. Select study session media mixes
7. Identify number of learning objectives in each medium

Steps 2 through 7 deal with study session media issues; the remaining steps, 8 through 11, deal with device media selection.

8. Identify device session participation requirements, e.g., displays, mock-ups, schematic representations, etc.
9. Classify objectives according to equipment (training and actual) compatibility requirements
10. Group objectives to arrive at an optimal set of training descriptions.
11. Determine final trainer configuration by assigning learning objectives to training devices

Post, Price and Diffley (1976) have developed a tool which aids in the selection of formats and media for presenting maintenance information (Post-Price Method). The method was developed with a view to implementation in the early stages of system development attempts to match technical manual formats with personnel, equipment and workspace characteristics.

The method is applied in five steps:

1. Identify maintenance actions and system condition data
2. Identify areas where standard formats are required (Standard Operating Procedures, maintenance complexity, time criticality, etc.)
3. Select formats for troubleshooting actions

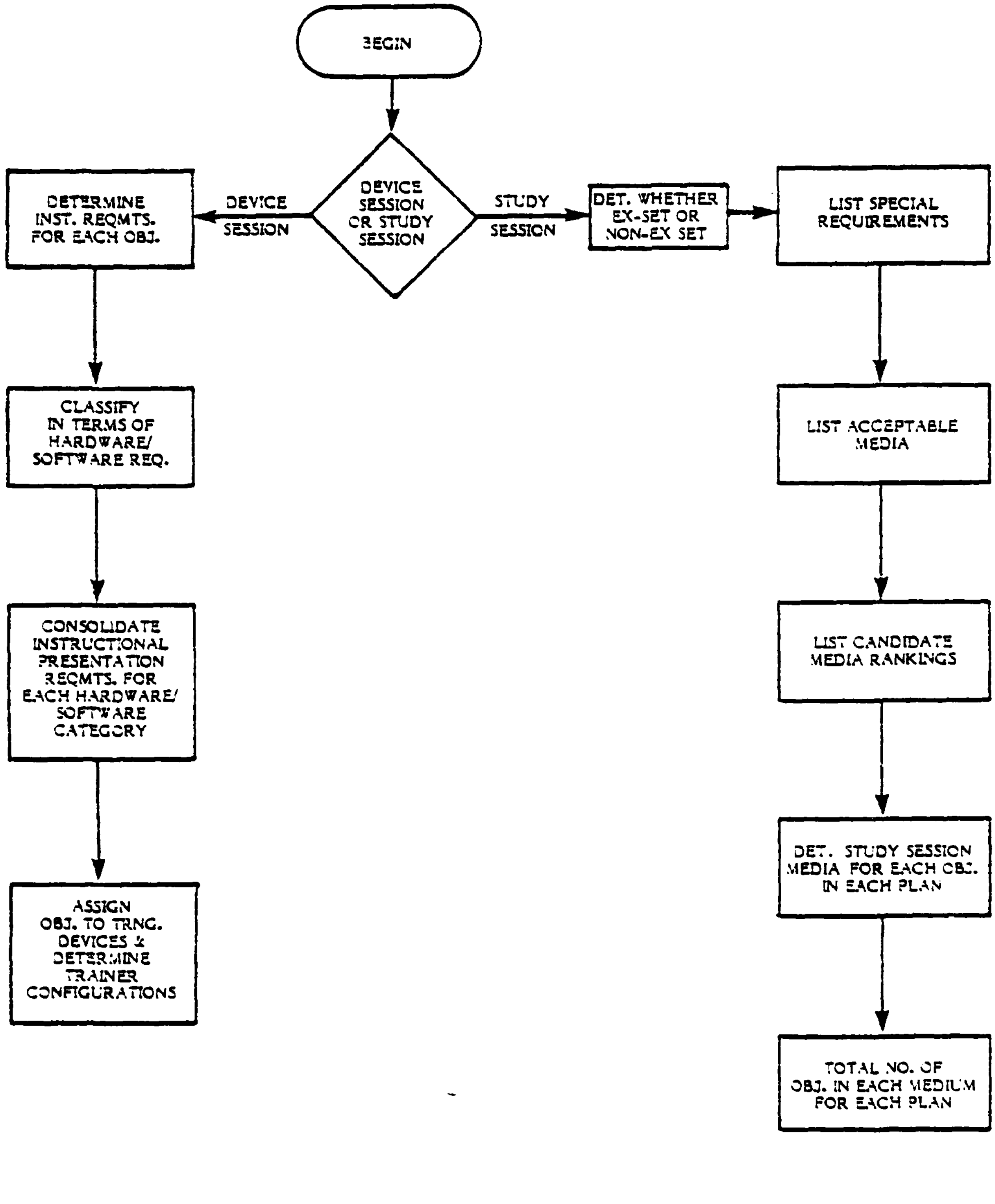


FIGURE 29
FLOW CHART FOR MEDIA ALTERNATIVES
(from Campbell and Hughes, 1978)

4. Select formats for removal/replacement actions
5. Establish Technical Manual (TM) support requirements

The first step requires the completion of a Task Identification Matrix (Figure 30), which identifies the types of maintenance actions required for given components being supported. A procedure is provided for the selection of formats based on cost, available formats, system computations (troubleshooting complexity, personnel turnover, etc.). A guide to, and recommendations for, Technical Manual Support requirements are provided. Three issues of TM support requirements are identified as being (1) ease of access, (2) ease of storage, distribution and updating, and (3) useability over extended use or adverse environments.

The method is applied according to the following considerations:

- Number of maintenance actions and conditions under which they are performed
- System considerations such as complexity, size, workspace and maintainer characteristics
- Combination of maintenance actions as homogeneous sets, to reduce TM complexity and developmental time and costs
- Innovative formats and media to best suit a particular system and its conditions
- TM preparation cost

FIGURE 30

TASK IDENTIFICATION MATRIX (TIM)
ADAPTED FROM POST, PRICE & DIFFLEY (1976)

MAINTENANCE FUNCTIONS / TOPDOWN BREAKDOWN (SYSTEM FUNCTIONS)	System Operational Check	Troubleshoot	Remove	Install	Adjust	Inspect	Calibrate
Hydraulic	X						
Hydraulic Subsystem #1	X	X					
Check valve			X	X			
Drain valve						X	
Filter			X	X			
Feeder valve					X		
Hydraulic Subsystem #2	X	X					

3.3 HFE Technologies Applicable During Full-Scale Engineering Development Phase

The major human engineering efforts during this phase consists of evaluating design concepts generated during the Demonstration/Validation phase, limited redesign of concepts and determination of HFE design criteria and procedures. Most of the technologies applicable during this phase have been implemented during the earlier acquisition phases, e.g., IPISD, Task Analysis, HEDGE, HFTEMAN, CAFES, MIL HDBK 472, etc.

Task Equipment Analysis

Task Equipment Analysis (TEA) is applied to describe and analyze tasks demonstrating how an operator/maintainer interacts with actual equipment. A TEA format is presented in Figure 31. The analyses typically lists:

- Tasks to be performed
- Associated controls/locators
- Method of control activation
- System responses
- System response time
- Associated displays/locators
- Display indicators
- Job aids/tools/test equipment (for maintenance TEA)

TEA can serve as a means of ensuring that all operational and performance requirements associated with the equipment are satisfied by the tasks.

Timeline Analysis

Timeline Analysis provides indications of temporal relationships among tasks and also indicates the duration of individual tasks. The technique is relatively easy to apply and can be very useful in identifying high and low operator load at various points in a task sequence. In application, tasks are sequentially listed (on a formal timeline sheet) in a column form, task duration time estimates are indicated by a bar graph, at the appropriate task initiation and termination points along the time (X-axis) dimension. At any point of time during a task sequence for an operator, the analysis can indicate:

- Number of concurrent tasks
- Rapidity of task performance, and
- Operator overload.

The analysis can be applied for any level of detail required, e.g., gross tasks such as "monitor," "verify," etc., or refined task elements demonstrating task completion medium,

FIGURE 31
EXAMPLE TASK EQUIPMENT ANALYSIS

MISSION SEGMENT ____________ FUNCTION ____________ CYCLE ____________

Task	Associated Control	Control Location	Method of Activation	System Response/ Time	Associated Display	Display Location	Display Indication	Remarks

e.g., "right hand-depress 'launch'." The more general task level is usually selected; however, since the detailed task element timeline is both difficult to develop and interpret. Examples of timelines are presented in Figures 32 through 34.

Workload Estimation

Workload estimation techniques and analyses that are applicable during the Full-Scale Engineering Development Phase differs greatly from the techniques previously reported. The techniques reported earlier (such as SW models, CAFES WAM) rely on judgments, task analysis to predict operator workload interacting with evolving systems. The present techniques measure (to some extent) workload of an operator interacting with hardware.

Wierwille and Williges (1978) have recently surveyed and analyzed operator and workload assessment techniques. Twenty-eight separate techniques were categorized into four separate groups. These four groups are:

- Subjective opinions
- Spare mental capacity methods
- Primary task measures, and
- Phsysiological measures

For each of the 28 techniques, theory, background, methods and apparatus and areas of application are discussed. Subjective opinions as a means to measure or estimate workload entails the use of rating scales, structured questionnaires, interviews, etc. Spare mental capacity methods vary somewhat in nature, but generally they require that a task be exercised while operational tasks are being executed, i.e., an additional task not related to system operation is performed. The assumption is that if operational task load is high, the additional task cannot be completed successfully, if at all. These additional tasks can be such things as time estimation, tracking, etc. Primary task measures attempt to measure mental workload as a function of primary task performance. A change in operator performance indicates an increase in mental workload. Physiological measures use physiological responses of an operator as a measure of workload. As workload changes, bodily responses are deemed to change also. Physiological measures can be used singly or in combination. Examples of physiological measures are: respiratory activity, circulatory activity, galvanic skin responses, EEG data, etc.

3.4 HFE Technology Assessment

The HFE technology assessment reported here is concerned with the degree to which the outputs of a particular HFE method or technique satisfy Human Factors Engineering

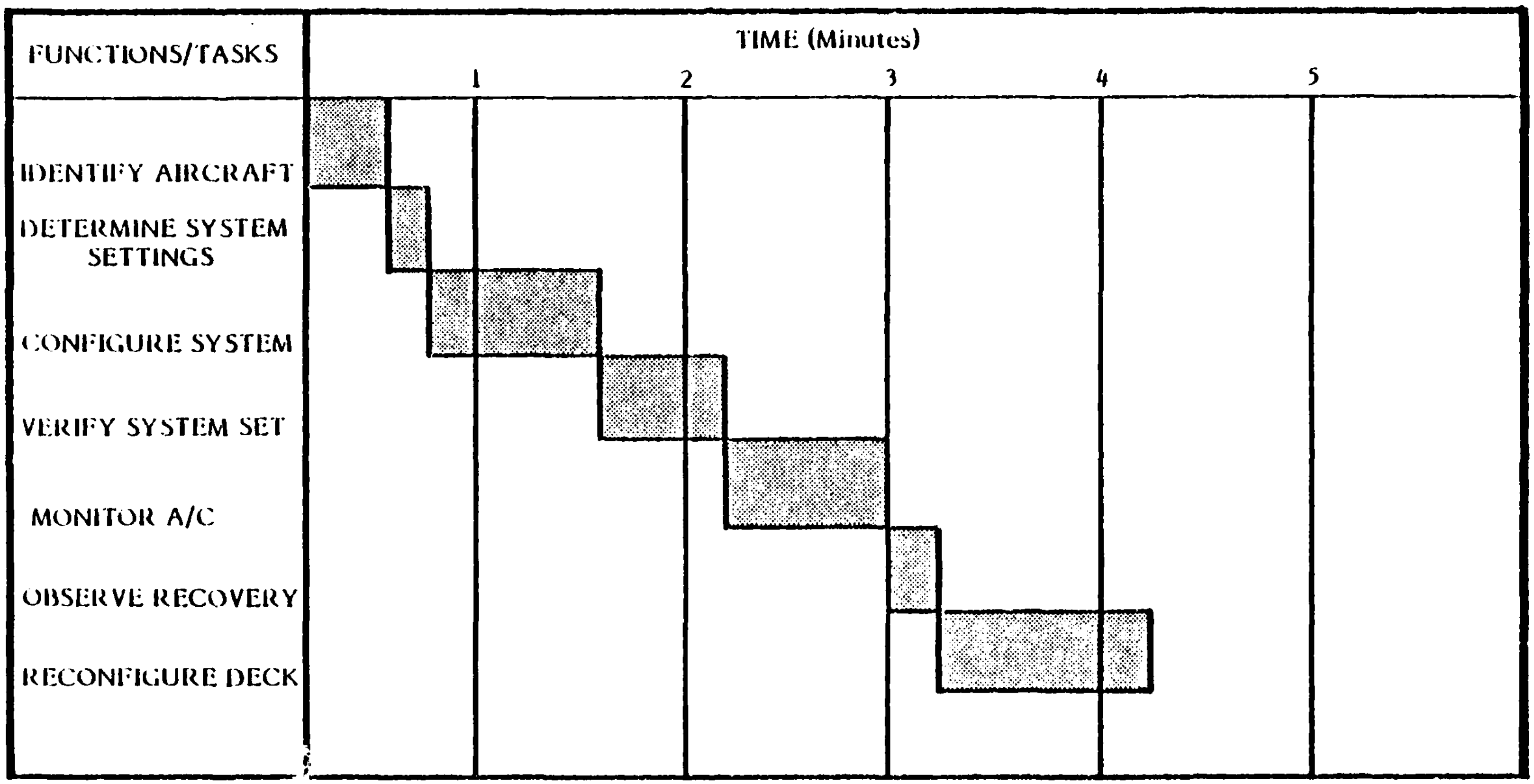


FIGURE 32
TIMELINE SHEET

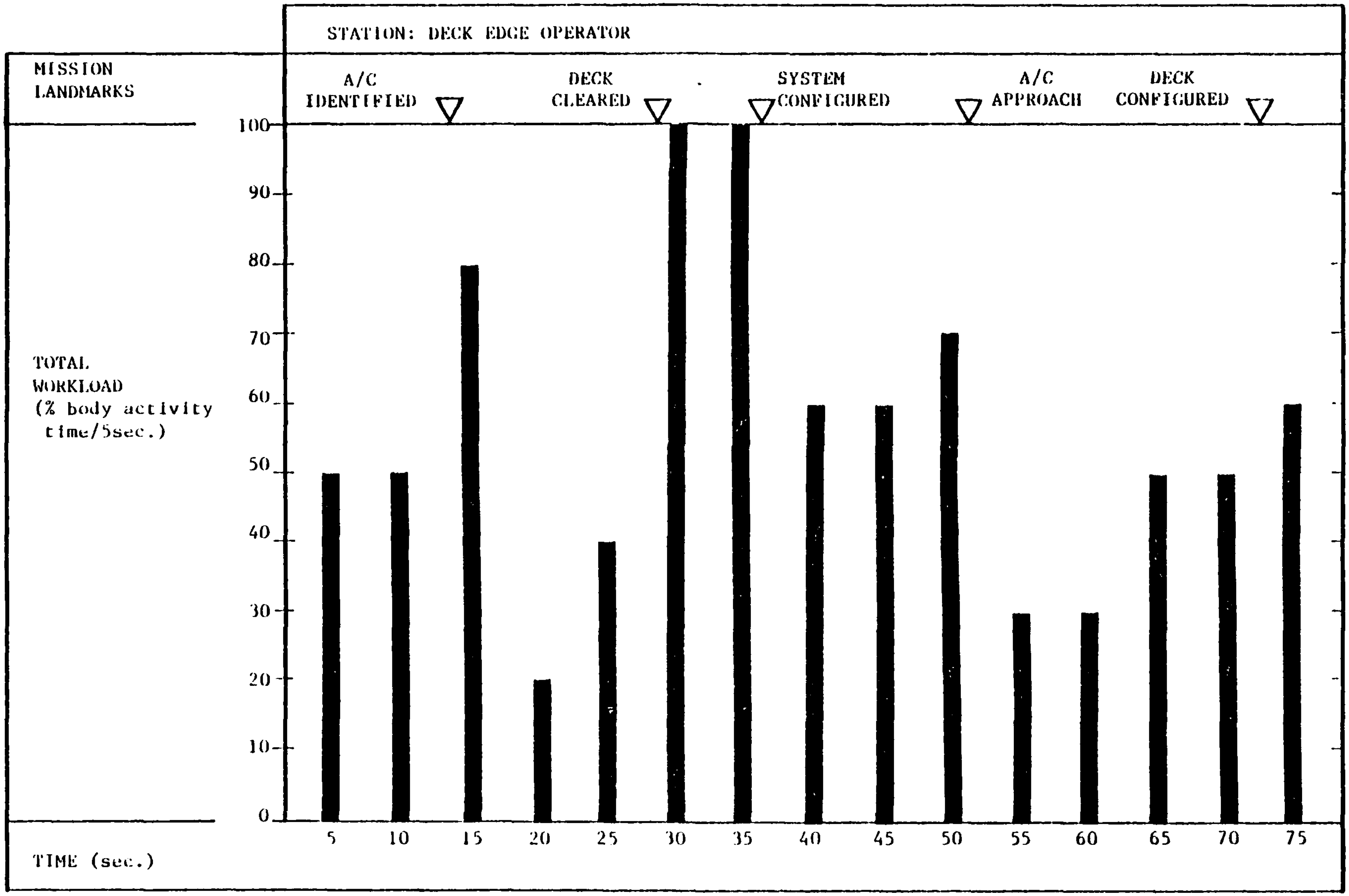


FIGURE 33
BODY ACTIVITY TIMELINE

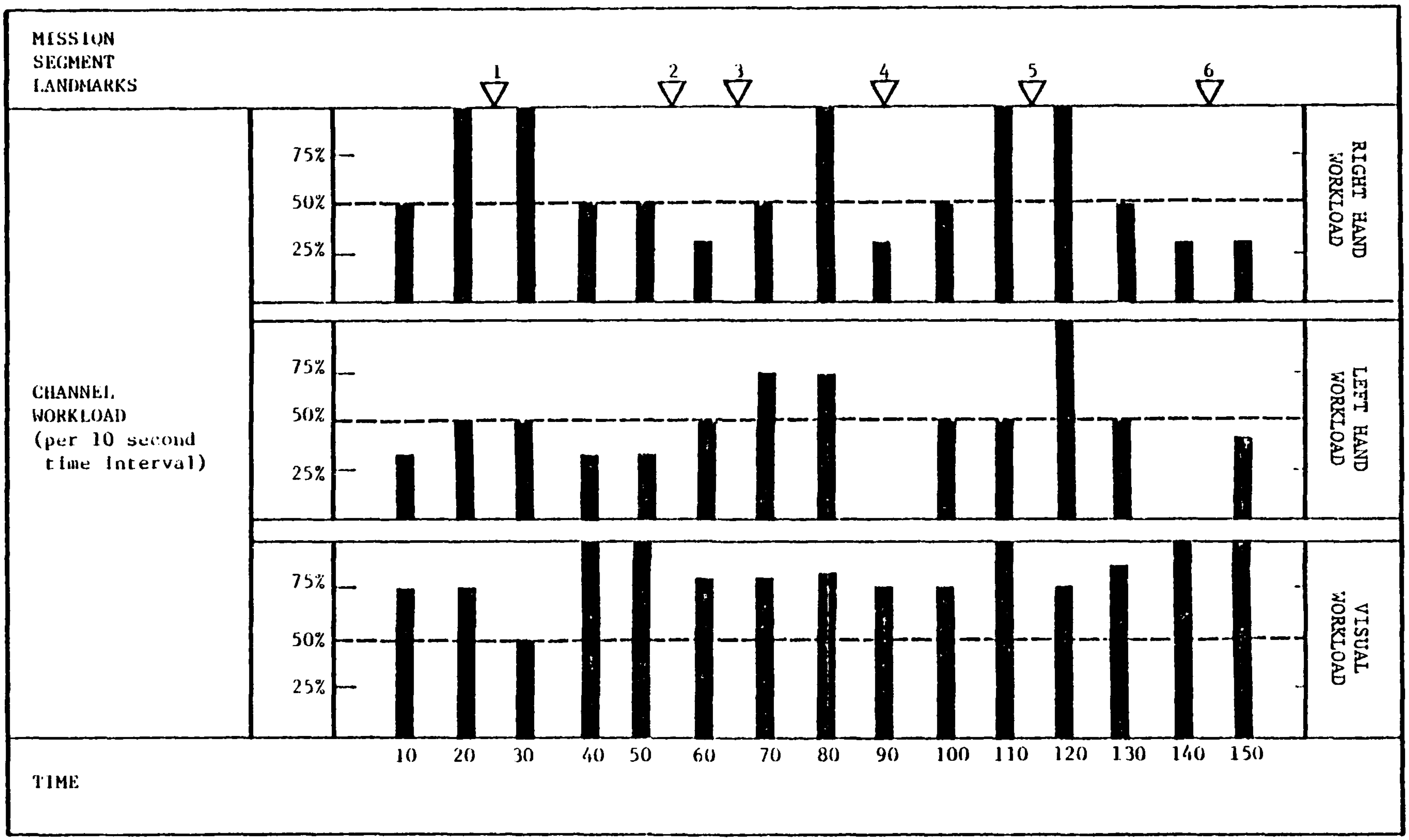


FIGURE 34
CHANNEL ACTIVITY TIMELINE

requirements shown in Figure 1. The assessment is not concerned with the procedure by which data are generated, synthesized or analyzed in order to achieve those outputs.

Table 18 and Figure 35 achieve the purposes of this technology assessment. Table 18 describes, for each technology:

- Technology type
  - descriptive
  - analytic
  - design
  - evaluation
  - diagnostic
  - integrative, and/or
  - data
- Application
- Inputs and outputs
- Cost
- Impact on system design
- Alternative technologies
- Source
- Special notes

The technology type entry in Table 18 refers to the overall objectives of the technology, description, analysis, etc. The distinction between evaluative and diagnostic technologies is made since all evaluation technologies do not diagnose problem areas within a design scheme, but rather only evaluate the total design as acceptable or not acceptable. Application refers to the method(s) by which the technology is applied, e.g., computer, hand calculations, drawings, etc. Cost is considered to be high (H), medium (M) or low (L), depending on method of application and complexity of the technique. Cost is, however, difficult to estimate, particularly with the computerized techniques. Invoking a computer simulation for a very small or simple system will obviously be more expensive than hand techniques, but many manual techniques as applied to complex systems with highly involved human operations are similarly unfeasible. At what point certain manual techniques become less cost beneficial than the computerized methods cannot be determined; however, since this paper deals with major weapon systems, cost considerations may begin to favor the computerized techniques, thereby rendering cost judgment tenable. Impact on system design, like cost, is judged to be high, medium or low, depending on the manner and frequency which output data of a technique or method is used to satisfy HFE requirements. Alternative technologies are those which may be used in lieu of the particular method being assessed, e.g., have similar outputs, purposes, goals, etc. Alternative technologies may vary in terms of cost, system-specific applicability,

and so on. Therefore, alternate technologies are in no way considered in this report as "interchangeable."

Figure 35 shows, for each technology, its applicability to specific HFE requirements shown in Figure 1.

Specific techniques are listed in the column; HFE requirements are the row entries. Where a column entry meets a row entry the following apply:

- No entry indicates that there is no relationship between the technology and requirement
- A "■" indicates that the column technique is applicable to the row requirement
- A "▲" entry indicates that the row entry is input to the column technique.

TABLE 18
HFE TECHNOLOGY ASSESSMENT

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
Mission Analysis	• Descriptive • Analytic	• Manual	• Mission data	• Mission Scenarios • Mission Profiles	M	M			
Functional Analysis	• Descriptive • Analytic	• Manual	• Mission analysis • Systems concepts • Similar systems data • STO data	• Functions • Functional Sequences • Functional Dependencies	M	H			
SAIM	• Analytic	• Manual	• Systems concepts • Similar systems data • STO	• System Functional • System Requirements • System Functions	M	M	• Functional Analysis		
FBD	• Descriptive • Analytic	• Manual • Graphical	• Functional • Functional	• System Functions • Functional Sequences • Functional Dependencies	M	M	• Functional Analysis		• Good potential for computerization using graphics terminal • FBD really supports Functional Analysis
Environmental Analysis	• Analytic	• Manual	• Mission Analysis • Functional Analysis • Similar systems data	• Environmental Conditions potentially degrading human performance	L	M			• Potential for developing computerized data base
Requirements Analysis	• Analytic	• Manual	• Mission Analysis • Functional Analysis • FBD	• Operator - performance requirements - information requirements - decision requirements	M	M			

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
Evaluation Matrix	• Design • Data • Integrative	• Manual	• Functional Analysis • Environmental Analysis • FBD • Requirements Analysis	• Man-Machine Functional Allocation Schemes	M	H	• Relative capabilities list	AFSC DH 1-3	
Relative Capabilities List	• Design • Data • Integrative	• Manual	• Functional Analysis • Environmental Analysis • FBD • Requirements Analysis	• Man-Machine Functional Allocation Schemes	M	H	• Evaluation Matrix	Varied	
Task Analysis	• Description • Analytic • Design • Evaluation	• Manual	• FBD • Functional Allocations • Requirements Analyses	• Task descriptions (detailed)	M	H	• TA/OSD • OSD	Many	• Locks standardization
TA-OSD	• Descriptive • Analytic • Design • Evaluation	• Manual • Graphic	• Task Analysis • OSD • Requirements Analysis • Functional Allocations	• Task Sequences • Task Data	M	H	• OSD • Task Analysis		• Excellent Design Tool • Highest applicability is toward single operator systems • Less suitable for computerization than normal OSD

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
A-OSD	• Descriptive • Analytic • Design • Evaluation • Diagnostic	• Mechanical printer	• FBD • Functional allocations • Task analysis • Requirements analysis • Task sequences	• Task sequences • Task dependencies • Syncronization and phasing of events • Operational and communi-cations net-works and links • Operational timeline • Equipment be-havior	M	H	• OSD (Manual)	NOSC & NPRDC	• May be valuable for developing TA/OSD
Decision/Action Diagram	• Analytic • Design	• Manual • Graphic	• FBD • Decision requirements	• Decision tree	M	M	• OSD • Task analysis • TA/OSD		• Can supplement OSD and task analysis • Potential for com-puterization
HFE Principals and criteria	• Design • Analytic • Evaluation	• Manual • Data		• Data is applied to design	L	H		Various	
OSD	• Descriptive • Analytic • Design • Evaluation • Diagnostic • Integrative	• Manual • Graphic	• FBD • Functional allocations • Task analysis • Requirements analysis • Task sequences	• Task sequences • Task dependencies • Syncronization and phasing of events • Operational and communi-cations networks • Operational timeline • Equipment behavior	H	H	• Task analysis	Several	• Highly useful tech-nology • Good potential for computerization to help reduce costs incurred by iterating complex diagrams and links

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
Link Analysis	• Design • Integrative	• Manual	• OSD • Task analysis • Requirements analysis	• Workspace layout schemes	L	H	• S-OSD		
Correlation Matrix	• Analytic • Design • Integrative	• Manual	• OSD • Task analysis • Requirements analysis	• Number and importance of station links	L	M			• Supports Link Analysis
AIR Data Store	• Design • Evaluation • Data	• Manual	• Control requirements • Display requirements	• *Predicted* control/display execution time • Predicted human reliabilities using specific controls/display • Total mission time predictions • Total Mission reliability predictions	M	M		American Institute of Research	• Mission Time and reliability predictions made solely as a function of predicted control and display operation times and reliabilities • Most applicable to stations requiring minimum information processing and decision making.
CRAFT	• Design	• Computer	• Source panel layout • Control and display use frequencies • Eye/hand motion rate • Eye/hand workload data	• Panel layout minimizing visual and motor transitions	H	M	• WOLAP • Linear Program Mins	NOSC	• Can be applied at component, subpanel, or panel levels • Generates panel designs

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
WOLAP	• Design • Evaluation	• Computer	• Initial panel layout • Panel components • Component weights (importance) • Frequency of control/display use	• Three panel layouts, according to component usage, weights, and visual/motor transitions	H	M	• CRAFT • Linear Programming	University of Waterloo, Ontario, Canada	• Can be applied at component, panel, or subpanel levels
Linear Programming	• Design	• Manual	• Component frequency of use • Visual transitions • Component spacing	• Panel configuration minimizing visual transition distances	M	L	• WOLAP • CRAFT	University of Michigan	• OSD
CAFES CAD	• Design • Evaluations • Diagnostic	• Computer	• Workspace layouts • Reach envelopes • Workspace characteristics • Visual reference points	• Escape envelope penetrators • External vision capabilities • Deviations in reach distances • Visual distances	H	H	• CAFES CGE	NADC	• Specifically constructed for aircraft systems but may be applicable to others • Good for emergency escape evaluations
DEI	• Evaluation	• Manual	• Control/display links • Controls data • Displays data • Task data	• Figure of merit for displays ability to provide an operator with information	M	M	• APS	Applied Psychological Services	

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
APS	• Design • Evaluations	• Manual	• Subjective judgments made according to statements relating to dimensions of displays (in a multidimensional scaling)	• User opinions	M	M	• DEI	APS	
HECAD	• Evaluation • Diagnostic • Data	• Computer	• Task data • Panel/console data	• Component operability (time and human reliability) • Transfer times (visual and motor)	H	H		AMRL WPAFB	• Evaluates panel layouts as a function of motor/visual transfer
TX-105	• Evaluations • Diagnostic	• Computer	• Cockpit geometry • Control/Display layouts • Task data	• Workload estimations • Estimation of system effectiveness in terms of human reliability	H	H	• SAINT	Boeing Aerospace	• Designed for evaluating aircrew stations
THERP	• Evaluation	• Manual	• Task data • Estimated task error rates • Performance shaping factors	• Prediction of system effectiveness decrement as a function of human errors	M	M		Sandia Labs	

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
TLA-1	• Evaluation	• Computer • Graphics plotter	• Task data • Channel activity for task execution	• Numerous operator workload reports	H	H	• TY-105 • CAFES-WAM • SW Models • SAINT	Boeing Aerospace	• Timeline programs
TEPPS	• Evaluation	• Computer	• System description • Task data • Task times • Task reliabilities	• Task execution time estimates • Estimated task reliabilities	H	H	• THERP • HECAD	BuPers	
SW 1-3 SW 4-20 SW 20-99	• Evaluation • Diagnostic	• Computer	• Mission data • Task execution times • Operator characteristics • Task characteristics • Time and probability distributions	• Areas of operator overload	H	H	• HOS	APS	• Monte Carlo simulation. Outputs distributions of Mission times and successes/failures • Different applications than HOS, CAFES • HOS offers deterministic outputs
CAFES WAM	• Evaluation • Diagnostic	• Computer	• Mission analysis • Mission phase timeline • Task channel activities • Task data	• Areas of operator • System activity time • Tasks contributing to workload	H	H	• TLA-1		• Basic objective of WAM to evaluate functional allocations effects on workload • WAM is more sophisticated than TLA-1

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
HOS	• Evaluation • Diagnostic	• Computer	• Mission analysis • Detailed task data • Control/Display data • Procedural data • Hardware characteristics • Information absorption times	• Timelines • Channel activity reports • Device usage • Operational link data	H	H	• SW Models		• Deterministic output • Simulates a good deal of different operator behavior • Concerned primarily with time history of the system • Highly sophisticated technique
SAINT	• Evaluative • Diagnostic	• Computer	• Detailed definition of task networks • Resources • Task data • Task priorities • System status variables	• Mission success data • Task time data • Mission times	H	H	• CAFES WAM • TLA-1	AMRL, WPAFB	• Monte Carlo technique • Primarily interested in time history of the system • Doesn't simulate human characteristics (fatigue, etc.)
Anthropometrics	• Data	• Data	• Data	• Criteria	M	H		various	
CAR	• Design • Evaluation • Diagnostic • Data	• Computer	• Workspace definitions • Population characteristics	• % population excluded by workspace design	H	M	• Data bases • CAFES CGE	NADC	• Monte Carlo technique • Specifically designed toward aircraft systems
COMBIMAN	• Design • Evaluation • Diagnostic • Data	• Computer • Keyboard • CRT • light pen	• Workspace dimensions • Population dimensions • Bodily restrictions (optional)	• Successful/unsuccessful reach	H	H	• Data bases	University of Dayton Research Institute	

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
CAFES CGE	• Evaluation • Diagnostic • Data	• Computer	• Cockpit data • Controls data • Eye reference points • Task sequences • Control shapes data	• Cockpit reach infeasi- bilities • Compliance with Mili- tary Standards and specifica- tions • Task accomplish- ments	H	H	• Data bases	NADC	• Offers data regarding compliance with standards
ORACLE	• Evaluation • Diagnostic	• Computer	• Information input rates • message initiation and response times • message priorities	• Information overload points	H	H		Westinghouse	• Essentially deals with information overload
HFTEMAN	• Evaluation • Diagnostic • Data	• Manual	• System descriptions • Task data • Requirements data	• Violations of of HFE design principals and criteria • Performance evaluations • T&E plans	M	H	• HEDGE	PMTC	• Provides comprehen- sive T&E guidance and test materials

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
HEDGE	• Evaluation • Diagnostic • Data	• Manual	• System definitions and character-istics • Task data	• Assessments of criteria compliance • Operability maintain-ability Training evaluations • Environmental analysis	M	H	• HFTEMAN	Army TECOM	
HFE Design Checklists	• Evaluation • Diagnostic	• Manual	• Design criteria • System design	• System design compliance with criteria	M	H			
HFE Task Checklists	• Evaluation • Diagnostic	• Manual	• Task Sequences	• Identification of overload • Identification of inadequate operability/ maintain-ability design	M	H			
FDI	• Evaluation	• Manual	• Crewman judgments concerning equipment design	• Effectiveness of man-machine interface	M	H		PMTC	
HFE Kits	• Evaluation	• Hardware			H	H		Perceptronics	
TART/Video Monitoring	• Evaluation • Diagnostic	• Hardware • Manual	• TA/OSD • Operator activities	• Error identification • Procedural Verification	M	H			Video recording of operational and/or maintenance procedures.

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
ERUPT	• Evaluation	• Manual	• Observed equipment reliabilities (from similar systems, or test data)	• Estimated probability of detection/ correcting an equipment failure • Estimated probability that maintenance does not induce failures	M	L		• Operations Research, Incorporated	
Multiple Correlation	• Design • Evaluation	• Manual	• Similar system reliability data (MTTR) • Similar system personnel data	• Identification of personnel requirements that may influence system reliability	M	M		Operations Research, Incorporated	As ERUPT uses operational data to infer developing system reliability
. ow Chart Maintainability Prediction	• Design • Evaluation	• Manual	• LOR analysis • FMEA • Troubleshooting diagram • MIL HDBK 472 data	• Estimated maintenance times of electronic circuits	M	M			
MONTE	• Analytic • Design	• Computer	• Decision tree • Decision probabilities	• Estimation of mission reliability	H	M			• Actually a JPA/ training device • Monte Carlo technique • Samples system output as a function of decisions mode

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
PAARS	• Evaluation • Diagnostic	• Hardware, Manual	• Operational procedures	• Procedures verification	M	M	• Video monitoring		• Radio system monitoring of operators
Allocation of Man-Machine Reliability	• Design	• Manual	• Minimum acceptable mission reliability • Minimum acceptable operational readiness • Maximum cost • Equipment reliabilities • Human reliabilities	• Acceptable mission reliability and operational readiness at lowest cost	M	M			• Much data is borrowed from similar systems or subjectively determined • Purpose is to optimize reliabilities (human MTTR, machine-MTBF) with cost constraints
Probability compounding	• Design • Evaluation • Data	• Manual	• Maintenance task data • Navy maintenance rating	• Estimated probability of maintenance Task success	L	M	• SW Models • MIL HDBK 472 • ERUPT		• Contains predictive data
MIL HDBK 472	• Design • Evaluation • Data	• Manual	• Maintenance task • Equipment reliability	• Indications of system maintainability	L	M	• Probability compounding • ERUPT • FC Maintainability prediction		• Contains four separate procedures and some support data

TABLE 18
(Continued)

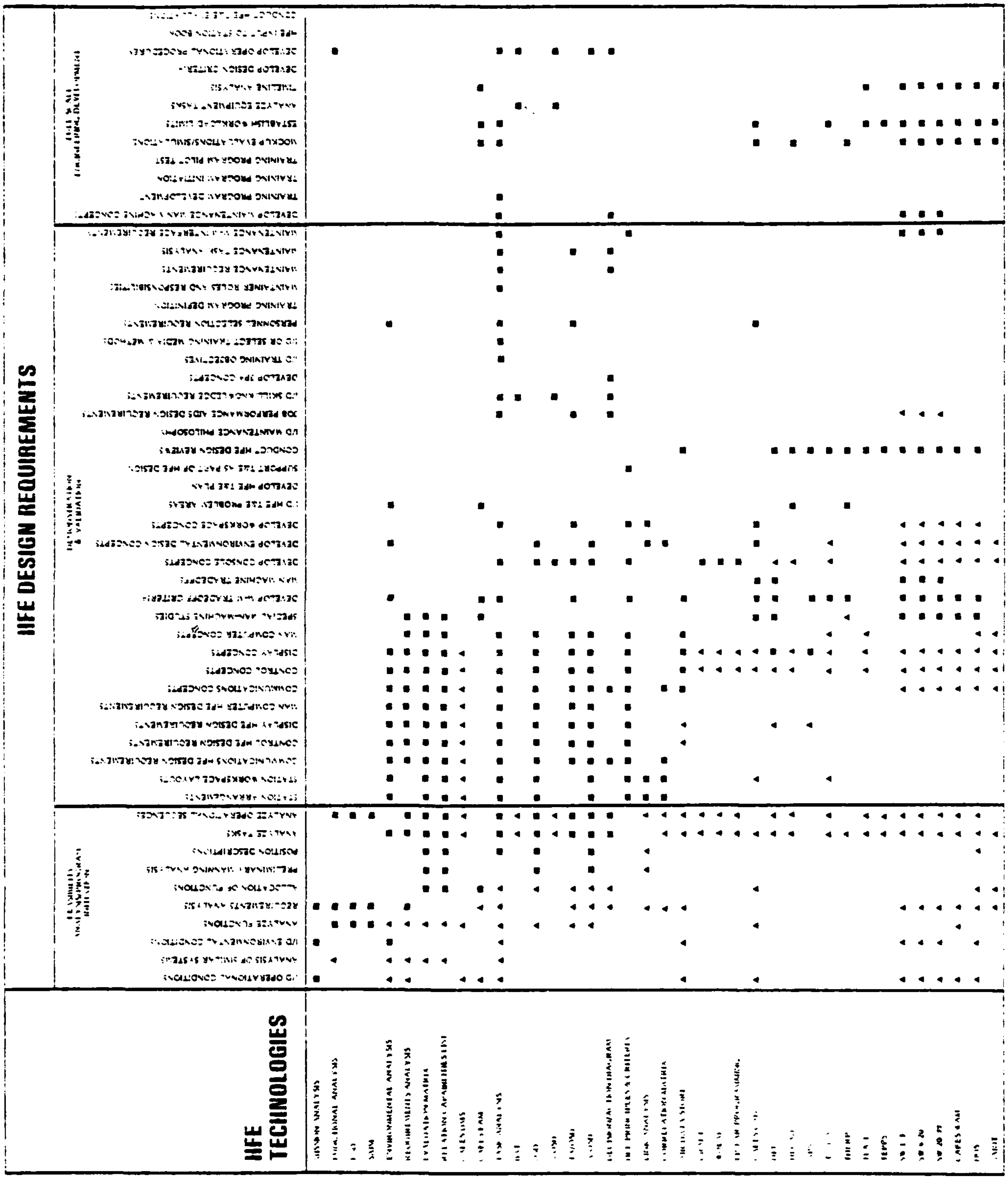
Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
IPISD	• Design • Methodology	• Structures application of training technologies		• Training system			• ISD Models		• Best described perhaps as a management tool and a methodology
Training Requirements Analysis	• Analytic	• Manual	• Task analysis • Requirements analysis • JPA requirements	• Learning objectives • Training objectives • Skill/knowledge requirements	M	H	• Job Analysis		
Job Analysis	• Analytic	• Manual	• Position descriptions • Task analysis • Similar systems	• Training objectives • Skill and knowledge requirements	M	M			• Can be used to infer skill/knowledge requirements, training objectives from similar jobs in similar systems.
MAP	• Design	• Manual	• Tasks and task characteristics	• Training system tradeoffs (personnel selection, training, JPAs and TMs)	L	M			
TECEP	• Design • Data	• Manual	• Training objectives	• Training media selections	M	H	• Campbell & Hughes Method	NTEC	• Helps select cost effectiveness media (9-step procedure)

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
Campbell and Hughes	• Design	• Manual	• Training objectives	• Training media mixes	M	H	• TECEP	• Course-ware, Inc.	• 11-step procedure • Helps select study and device type media
DH 1-3	• Design	• Manual	• Skill/knowledge requirements	• Training/ SPA decisions	M	M		AFSC	
JPA AATTA	• Data	• Manual			M	M			• Troubleshooting technique
Booher	• Data	• Manual			M	M			• JPA Model
FOMM	• Data	• Manual			M	M			• JPA Model
TREES	• JPA Data	• Computer	• Tree structured maintenance data						• Could also be used as a maintenance trainer
Post Price	• Design	• Manual	• Maintenance task data • Task identification matrix	• Media selection	M	M		Biotechnology	
TEA	• Analytic • Evaluation	• Manual	• Task data • Equipment data	• Man-machine interactions	M	M			
Workload Analysis	• Evaluation • Diagnostic	• Equipment • Manual • computer	• Subjective judgments • Psysiological monitoring • Direct observation	• Indications of workload	M-H	M-H		Various	

TABLE 18
(Continued)

Technology	Type	Application	Inputs	Outputs	Cost	Impact on System Design	Alternative Technologies	Source	Notes
Timeline Analysis	• Description • Analytic • Evaluation	• Manual	• Mission analysis • Workload analysis	• Operational time history	L	M		Various	



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HFE DESIGN REQUIREMENTS

HFE TECHNOLOGIES

FEASIBILITY ANALYSIS/PROGRAM INITIATION

HFE TECHNOLOGIES	I/D OPERATIONAL CONDITIONS	ANALYSIS OF SIMILAR SYSTEMS	I/D ENVIRONMENTAL CONDITIONS	ANALYZE FUNCTIONS	REQUIREMENTS ANALYSIS	ALLOCATION OF FUNCTIONS	PRELIMINARY MANNING ANALYSIS	POSITION DESCRIPTIONS	ANALYZE TASKS	ANALYZE OPERATIONAL SEQUENCES
ANTHROPOMETRIC DATA										
CAPE										
COMBIMAN			▲							
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[illegible]	▲		▲		▲				▲	
HFE DESIGN CHECKLIST	▲		▲						▲	▲
HFE TASKS CHECKLIST	▲		▲						▲	▲
ERROR LIKELIHOOD ANALYSIS	▲		▲						▲	▲
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FILM/VIDEO RECORDING									▲	▲
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MIL-HDBK-472		▲		▲		■				
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DEMONSTRATION & VALIDATION

HFE TECHNOLOGIES	STATION ARRANGEMENTS	STATION WORKSPACE LAYOUTS	COMMUNICATIONS HFE DESIGN REQUIREMENTS	CONTROL HFE DESIGN REQUIREMENTS	DISPLAY HFE DESIGN REQUIREMENTS	MAN COMPUTER HFE DESIGN REQUIREMENTS	COMMUNICATIONS CONCEPTS	CONTROL CONCEPTS	DISPLAY CONCEPTS	MAN COMPUTER CONCEPTS	SPECIAL MAN-MACHINE STUDIES	DEVELOP M/M TRADEOFF CRITERIA	MAN MACHINE TRADEOFFS	DEVELOP CONSOLE CONCEPTS	DEVELOP ENVIRONMENTAL DESIGN CONCEPTS	DEVELOP WORKSPACE CONCEPTS	I/D HFE T&E PROBLEM AREAS	DEVELOP HFE T&E PLAN	SUPPORT T&E AS PART OF HFE DESIGN	CONDUCT HFE DESIGN REVIEWS
ANTHROPOMETRIC DATA		■												■	■	■	■		■	
CAPE		▲												▲	▲	▲	■		■	■
COMBIMAN		▲												▲	▲	▲	■		■	■
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HFE DESIGN CHECKLIST							▲	▲	▲	▲				▲			■	■	■	■
HFE TASKS CHECKLIST							▲	▲	▲	▲							■	■	■	■
ERROR LIKELIHOOD ANALYSIS							▲	▲	▲	▲				▲	▲		■	■	■	■
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FILM/VIDEO RECORDING							▲	▲	▲	▲				▲			■	■	■	■
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DEMONSTRATION & VALIDATION (continued) / FULL SCALE ENGINEERING DEVELOPMENT

HFE TECHNOLOGIES	I/D MAINTENANCE PHILOSOPHY	JOB PERFORMANCE AIDS DESIGN REQUIREMENTS	I/D SKILL/KNOWLEDGE REQUIREMENTS	DEVELOP JPA CONCEPTS	I/D TRAINING OBJECTIVES	I/D OR SELECT TRAINING MEDIA & METHODS	PERSONNEL SELECTION REQUIREMENTS	TRAINING PROGRAM DEFINITION	MAINTAINER ROLES AND RESPONSIBILITIES	MAINTENANCE REQUIREMENTS	MAINTENANCE TASK ANALYSIS	MAINTENANCE MAN/INTERFACE REQUIREMENTS	DEVELOP MAINTENANCE MAN MACHINE CONCEPTS	TRAINING PROGRAM DEVELOPMENT	TRAINING PROGRAM INITIATION	TRAINING PROGRAM PILOT TEST	MOCKUP EVALUATIONS/SIMULATIONS	ESTABLISH WORKLOAD LIMITS	ANALYZE EQUIPMENT TASKS	TIMELINE ANALYSIS	DEVELOP DESIGN CRITERIA	DEVELOP OPERATIONAL PROCEDURES	HFE INPUT TO STATION BOOK	CONDUCT HFE T&E EVALUATIONS
ANTHROPOMETRIC DATA																	■		■		■			■
CAPE																	■		■		■			■
COMBIMAN																	■		■		■			■
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4.0 HFE TECHNOLOGY SHORTFALLS

In this section, HFE technological shortfalls relevant to the following are discussed:

- Similar systems analysis
- Special environments
- Design criteria/military specifications and standards
- Complex workspace design
- Maintainability design and evaluation
- Test and evaluation
- Training system design

4.1 Similar System Analysis

Similar Systems Analysis represents an HFE requirement that has not experienced much intense interest in HFE R&D. The need for a proceduralized method of analyzing similar systems and subsystems has increased over the years since the development of computerized human and human-system simulators which rely on human and system reliability and time input data. These data, more often than not, are not available in either data bases or research literature. The result is that many subjective judgments on the part of HF specialists and hardware engineers are required to implement these man-machine models. Apart from the obvious data available for analysis of similar systems (manning levels, functional allocations, task sequences, etc.), detailed information may be acquired, e.g.:

- Mission segment times, timelines
- Task sequence duration time
- System, subsystem and component reliabilities
- Operator reliabilities
- Operator task loading
- Task execution times
- HFE design deficiencies
- Subsystem and component response times, etc.

A variety of tools exist for collecting such data, but are typically designed for shipboard data collection, and many of these are directed towards CIC (Combat Information Center) operations. Notables in this group include:

- OPREDS (Operational Performance Recording and Evaluation Data System)
- ADER (Automatic Data Extraction and Reduction)

- OPMS (Operator Performance Measurement System, directed towards radar tracking task performance measurement)

The basic method of operation of these techniques is the recording of control activations and display information for all controls and displays over time. The recordings are taken from the equipment directly, i.e., hardwired to controls and displays. The recordings can be played back to reconstruct actual operations, noting operational times, equipment activations, errors, etc., in a nonobtrusive fashion.

The chief difficulty in acquiring data with hardware such as this for certain major weapons systems (e.g., small aircraft) is the availability of space for equipment storage.

FLAG is a computerized data base of HE design deficiencies reported (via discrepancy sheets) for the P-3B/C, SH-2, S-3A, F-14, and F-18 aircraft (F-18 aircraft data are to be input as the data become available). FLAG is to be continually updated so as to be an aid in identifying HFE design problem areas for future aircraft acquisitions.

Specific HFE technology shortfalls relevant to similar systems analysis are:

- There is no general tool for collecting quantitative operational data from similar systems
- Beyond FLAG, which is directed solely towards identifying aircraft human engineering deficiencies, there is no readily available HFE data base concerning reported HFE design deficiencies inherent in specific systems or system classes.
- There is no proceduralized method (other than formal HFE T&E) to analyze similar systems in order to help identify developing system HFE design issues

Recommendations: based on the identified technology gaps relevant to similar systems analysis, the following recommendations are made:

- Determine the feasibility of modifying operational recording systems (such as OPREDS) such that they may offer a more universal applicability
- Determine the feasibility of establishing an HFE design deficiency report/retrieval system, similar to FLAG, for other classes of systems
- Examine the potential and feasibility of a similar systems and components evaluation methodology to assist in identifying potential design issues in developing systems. The methodology should address such areas as operability, maintainability, manning and training, system/mission reliabilities and component reliabilities

4.2 Special Environments

With the development of new technologies being incorporated into weapon systems, the human operator has been subjected to different and more demanding work environ-

ments. These technologies both introduce operators to these environments (space systems, high altitude flight, arctic environments, etc.) and subject operators to special environments (high acceleration aircraft, high vibration shipboard spaces and ships, radiation, etc.). Within the context of special environments, HFE issues such as performance degradation, environmental design, safety and personnel issues are addressed. For large, sophisticated systems, experimental research will be implemented to determine performance degradation, to evaluate environmental design, etc. For systems where such research cannot be justified or funded, HE methods and data will be relied upon to assist in developing environmental design concepts. Within this context, the following technology gaps are identified:

- A sufficient HFE data base relating to performance degradation as a function of environmental dimensions is not available.
- Personnel selection techniques for special environments are scattered and insufficient in terms of addressing a broad spectrum of environments.
- Anthropometric design methodologies (apart from aircraft stations) generally do not exist, particularly for such conditions as cold weather maintenance, accessibility design, etc.

Recommendations: specific recommendations to be made are as follows:

- While a good deal of research related to performance degradation in special environments has been (and is being) performed, it has not been reviewed, abstracted and presented in usable form. Development of an environmental design handbook for Navy systems, that encompasses somewhat special environments, is recommended.
- Many psychometric selection tools exist; however, general purpose test batteries directed at selecting personnel for special environments do not. It is recommended that such tools be developed.
- Computerized modelling of the anthropometry of military personnel have been developed (CAFES, CGE, COMBIMAN, CAPE, etc.). The thrust of hese models has been the simulation of aircraft stations. It is recommended that the feasibility of modifying some of these models in order to extend applicability to other system types be determined.

Kennedy (1978) has reported a program, at the Naval Aerospace Medical Research Laboratory detachment, New Orleans, and the Pacific Missile Test Center, known as PETER (Performance Evaluation Test for Environmental Research). The purpose of the program is to develop a human performance test battery for personnel selection and performance prediction in special environments.

4.3 HFE Design Criteria and Military Specifications and Standards

The following shortfalls have been identified regarding HFE design criteria and military specifications and standards:

- For many systems, due to space limitations, environments, cost constraints, etc., existing criteria and standards are not feasible and cannot be implemented.
- Research data often are conflicting with standards and criteria.
- Anthropometric standards often exclude a large proportion of the available manpower pool.
- Where special circumstances do not prohibit compliance with standards and specifications, they are inadequate in terms of addressing maintainability design, anthropometry, component selection and functional allocations, as a function of cost, relative reliabilities and availability.
- Military standards and specifications relating to, or affecting, HFE design are scattered throughout Human Engineering standards and specifications, NATO agreements, ILS plans, policy and standards, component standardization guidelines and so on.
- HFE proposal evaluation criteria and data are not available and source selections are therefore frequently made on a subjective basis.

Recommendations: the following recommendations are made with respect to the identified technology gaps and shortfalls:

- Experimentation and literature review in order to support or provide identification of needed change in Human Engineering standards and specifications
- Provisions for simulation and experimentation be established where standard and specification implementation is untenable
- Establishment of formal functional allocation guidelines in terms of relative man-machine cost and reliability for operability and maintainability design efforts.
- Determination of the feasibility of establishing an HFE data base encompassing all related military standards and specifications, HE design criteria, NATO agreements, etc., either in printed and bound or computer-based formats.
- Determine the feasibility of developing HFE proposal evaluation methods and criteria.

4.4 Complex Workspace Design

Technology advances and increased sophistication of major weapon systems increases the complexity of system operation and workspace design. Controls and displays, such as Head Up Displays (HUD), Voice Interactive Systems (VIS), potential for color CRT's, LEDs, LCDs, plasma displays, integrated controls, and computer generated

displays, have complicated the task of workspace design. For a design to develop workspace concepts minimizing operator cognitive, motor, auditory and visual workload, and maximizing human performance through workspace layout, a large effort is required. Constraints and controlling factors such as varying task sequences, environmental conditions, threats, requirements for emergency egress, etc., further complicate the effort. Specific HFE technology shortfalls relevant to the above are such that:

- There are no standardized methods which serve to define the role of man in automated systems.
- Current computerized workspace design tools do not accommodate the changing status of developing controls and displays, e.g., computer generated displays, multipurpose displays, multipurpose controls.
- Computerized workspace design tools (such as WOLAP and CRAFT) generally minimize visual and motor transition times as a function of task sequences and control and display criticality. Other factors that impact workspace layout, such as anthropometry, control and display type and complexity, etc, are typically not addressed.

A group of computerized techniques to assist in generating crewstation concepts, the Interactive Design Support Models (IDSM), is being developed at the Naval Air Development Center. The interactive programs will address:

- Panel space allocation (CUBITS)
- Control and display labelling and abbreviation (ABBREV)
- Crewstation assessment of reach (CAR)
- Operational sequences
- Functional grouping of controls and displays (GROUP)

In addition to the above, Lewis* at the Naval Oceans Systems Center is doing extensive work on the automation of OSDs using a computer and graphics terminal. A tool such as this could be highly useful and beneficial to human engineers, particularly as applied to complex operations.

Recommendations: based on the HFE shortfalls identified and the ongoing effort at NADC, the following recommendations are made:

- Identify the feasibility of incorporating additional workstation layout factors in advanced or developing computerized tools.
- Integrate computerized workstation design tools with computerized design evolution and evaluation tools (such as CAFES, Siegel-Wolf models, HOS, etc.)

* Personal communication with Mr. Warren Lewis.

AD-A125 462 HFE (HUMAN FACTORS ENGINEERING) TECHNOLOGY FOR NAVY WEAPON SYSTEM ACQUISITION(U) ESSEX CORP ALEXANDRIA VA C C BAKER ET AL. JUL 79 N00024-76-C-6129

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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

4.5 Maintainability Design and Evaluation

With the increasing complexity of naval combat systems additional demands are placed on system maintainers, particularly in the areas of diagnostics, component access, calibration and electronics repair. Traditionally, the role of the human engineer has been more or less to develop training systems given a system configuration and to subject a system to an HFE maintainability design evaluation. With respect to the above, the following HFE shortfalls are identified:

- Methods and techniques for incorporating HFE as part of maintainability design (particularly in the accessibility/arrangements area)
- Methods whereby mockups are used as part of evolutionary design early in the system configuration
- Sufficient maintainability design principles and standards in terms of generating maintenance concepts
- HFE principles and standards related to test bench design

Recommendations: the basic recommendation made is to examine the HFE aspect of maintainability as part of system design and determine in detail requirements for HFE methodologies which aid in generating maintainability designs. Specific recommendations are as follows:

- Determine the feasibility of developing computer-aided maintainability access and arrangement design tools similar to WOLAP, etc.
- Development of maintainability design evaluation tools, e.g., diagnostic tools that radiate areas of required redesign.
- Development of maintainability design handbook or similar to address issues such as:
  - access design
  - test bench design
  - tools design
- Identify and develop principles and standards relevant to generating maintenance design concepts.

4.6 Test and Evaluation

HFE T&E typically entails (1) assessments of the degree to which a system's design complies with design criteria along various dimensions such as display illuminations, control activation forces, etc., and (2) assessments of operator/maintainer performance (essentially relative to human reliability) of tasks and task sequencies given a system configuration. With regard to compliance with design criteria, physical measurements are usually taken (torque measurements, etc.) and checked for compliance with standards such

as MIL-STD-1472. The ultimate goal would be to help optimize human performance via standards compliance. However, as many systems cannot comply with standards (due to constraints such as space, volume, weight, cost), determinations of total system reliability and availability (viewing human reliability as an integral part) must be made with assessments of human performance in that system. In many systems these assessments are made via direct observations of task performance and operator/maintainer reporting techniques. Again, in some systems (notably, aircraft) direct observations are not possible (outside of mockups and simulators which cannot afford perfect environment fidelity) and, hense, subjective operator opinions are required. The major HFE technology shortfalls with regard to the above are:

- Where direct observation of task performance cannot be made, no adequate techniques or methods were identified for evaluating these systems .
- Insufficient data base for estimating operator/maintainer performance in lieu of standards compliance.

The Mission Operability Assessment Technique (MOAT) may aleviate the first technology gap. MOAT is being developed at Pacific Missile Test Center and the Naval Air Development Center, and is based in part on the Functional Description Inventory (FDI is in fact a part of MOAT development).

Recommendation: it is recommended that development of MOAT continue and be expanded for generalized use for systems other than a single seat jet aircraft.

4.7 Manning and Training

The all-volunteer armed forces concept has changed drastically the characteristics and availability of soldiers, sailors and airmen. As a result, manning and training have become far larger issues within the services than previously. The following technology shortfalls are identified relevant to manning and training:

- Fewer techniques exist for deriving early estimations of system specific manpower requirements.
- There are no standardized techniques for skill referenced job design.
- There are no techniques which integrate HFE design and training.

Relevant to the first shortfall, two methods which may soon be available are the Logistics Composite Models (LCOM) and the SHIPS II program. The LCOM model being developed by the Air Force Human Resources Laboratory will be useful in predicting maintenance manpower requirements for aircraft systems during development (Tetmeyer, et al, 1976). The Ship II model being developed at the Naval Personnel Research and Development Center is directed towards predicting total ship manning levels.

Recommendations:

- It is recommended that techniques towards integrating HFE and training system design be developed.
- It is recommended that standard methods for developing job designs based on skill requirements be developed.

APPENDIX A

LIST OF ACRONYMS

AIR	American Institute for Research
A-OSD	Automated Operational Sequence Diagram
APS	Analytic Profile System
	Applied Psychological Services
BAT	Behavioral Analysis of Tasks
CAFES	Computer Aided Functional Allocation Evaluation System
CAFES CAD	CAFES Computer Aided Design
CAFES CGE	CAFES Crewstation Geometry Evaluation
CAFES DMS	CAFES Data Management System
CAFES FAM	CAFES Functional Allocation Model
CAFES SWAM	CAFES Statistical Workload Analysis Model
CAFES WAM	CAFES Workload Analysis Model
CAR	Crewstation Assessment of Reach
CIC	Combat Information Center
CM	Corrective Maintenance
COMBIMAN	Computerized Biomechanical Man Model
CRAFT	Computerized Relative Allocation of Facilities Technique
CRT	Cathod Ray Tube
DCP	Decision Coordinating Paper
DEI	Display Evaluation Index
DH	Design Handbook
DIDs	Data Item Descriptions
DoD	Department of Defense
DP	Developmental Proposal
DNSARC	Department of the Navy System Acquisition Review Council
DSARC	Defense System Acquisition Review Council
DT&E	Development Test & Evaluation
ERU	Elementary Reliability Unit
ERUPT	Elementary Reliability Unit Predictive Technique
FBD	Functional Block Diagram
FC	Flow Chart
FDI	Functional Description Inventory
FFD	Functional Flow Diagram

FPJPA	Fully Proceduralized Job Performance Aids
HE	Human Engineering
HECAD	Human Engineering Computer Aided Design
HEDGE	Human Engineering Data Guide for Evaluation
HF	Human Factors
HFE	Human Factors Engineering
HFTEMAN	Human Factors Test & Evaluation Manual
HOS	Human Operator Simulator
HUD	Heads Up Display
IDSM	Interactive Design Support Models
ILS	Integrated Logistics Support
ILSMP	Integrated Logistics Support Master Plan
IPISD	Interservice Procedures ISD
ISD	Instructional Systems Development
JPA	Job Performance Aid
JPA AATTA	Job Performance Aid Augmented Action Tree Troubleshooting Aid
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LOR	Level of Repair
MAP	Means to Achieve Performance
MENS	Mission Element Need Statement
MIL HDBK	Military Handbook
MIL STD	Military Standard
MOAT	Mission Operability Assessment Technique
MTBF	Mean Time Between Failure
MTTR	Mean Time to Repair
NATO	North Atlantic Treaty Organization
OJCS	Office of the Joint Chiefs of Staff
OJT	On-the-Job Training
OPREDS	Operational Performance Recording and Evaluation Data System
OR	Operational Requirement
ORACLE	Operations Research and Critical Link Evaluation
OSD	Office of the Secretary of Defense
	Operational Sequence Diagram
OT&E	Operational Test & Evaluation

PETER	Performance Evaluation Testing for Environmental Research
PM	Program Manager
PMP	Program Master Plan
PPI	Personnel Performance Indices
R&D	Research & Development
RDT&E	Research, Development, Test & Evaluation
RFP	Requests for Proposals
RNO	Remaining Number of Opportunities
SAIM	Systems Analysis Integration Model
SAINT	Systems Analysis of Integrated Networks of Tasks
SECDEF	Secretary of Defense
S-OSD	Spacial OSD
STO	Science & Technology Objectives
SW	Siegel-Wolf
TA	Task Analysis
TA/OSD	Task Analysis/OSD
TART	Task Analysis Reduction Technique
TEA	Task Equipment Analysis
TECEP	Training Effectiveness, Cost Effectiveness, Prediction Technique
TEPPS	Technique for Estimating Personnel Performance Standards
TEMP	Test & Evaluation Master Plan
T&E	Test & Evaluation
THERP	Technique for Human Error Rate Prediction
TIM	Task Identification Matrix
TLA-1	Timeline Analysis Program - Model 1
TM	Technical Manual
VIS	Voice Interactive System
WOLAP	Workspace Optimization Layout and Planning

APPENDIX B

OMB CIRCULAR NUMBER A-109

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
WASHINGTON, D.C. 20503

April 5, 1976 CIRCULAR NO. A-109

TO THE HEADS OF EXECUTIVE DEPARTMENTS AND ESTABLISHMENTS

SUBJECT: Major System Acquisitions

1. Purpose. This Circular establishes policies, to be followed by executive branch agencies in the acquisition of major systems.

2. Background. The acquisition of major systems by the Federal Government constitutes one of the most crucial and expensive activities performed to meet national needs. Its impact is critical on technology, on the Nation's economic and fiscal policies, and on the accomplishment of Government agency missions in such fields as defense, space, energy and transportation. For a number of years, there has been deep concern over the effectiveness of the management of major system acquisitions. The report of the Commission on Government Procurement recommended basic changes to improve the process of acquiring major systems. This Circular is based on executive branch consideration of the Commission's recommendations.

3. Responsibility. Each agency head has the responsibility to ensure that the provisions of this Circular are followed. This Circular provides administrative direction to heads of agencies and does not establish and shall not be construed to create any substantive or procedural basis for any person to challenge any agency action or inaction on the basis that such action was not in accordance with this Circular.

4. Coverage. This Circular covers and applies to:

a. Management of the acquisition of major systems, including: ° Analysis of agency missions ° Determination of mission needs ° Setting of program objectives ° Determination of system requirements ° System program planning ° Budgeting ° Funding ° Research ° Engineering ° Development ° Testing and evaluation ° Contracting ° Production ° Program and management control ° Introduction

of the system into use or otherwise successful achievement of program objectives.

b. All programs for the acquisition of major systems even though:

(1) The system is one-of-a-kind.

(2) The agency's involvement in the system is limited to the development of demonstration hardware for optional use by the private sector rather than for the agency's own use.

5. Definitions. As used in this Circular:

a. Executive agency (hereinafter referred to as agency) means an executive department, and an independent establishment within the meaning of sections 101 and 104(1), respectively, of Title 5, United States Code.

b. Agency component means a major organizational subdivision of an agency. For example: The Army, Navy, Air Force, and Defense Supply Agency are agency components of the Department of Defense. The Federal Aviation Administration, Urban Mass Transportation Administration, and the Federal Highway Administration are agency components of the Department of Transportation.

c. Agency missions means those responsibilities for meeting national needs assigned to a specific agency.

d. Mission need means a required capability within an agency's overall purpose, including cost and schedule considerations.

e. Program objectives means the capability, cost and schedule goals being sought by the system acquisition program in response to a mission need.

f. Program means an organized set of activities directed toward a common purpose, objective, or goal undertaken or proposed by an agency in order to carry out responsibilities assigned to it.

g. System design concept means an idea expressed in terms of general performance, capabilities, and characteristics of hardware and software oriented either to

operate or to be operated as an integrated whole in meeting a mission need.

h. *Major system* means that combination of elements that will function together to produce the capabilities required to fulfill a mission need. The elements may include, for example, hardware, equipment, software, construction, or other improvements or real property. Major system acquisition programs are those programs that (1) are directed at and critical to fulfilling an agency mission, (2) entail the allocation of relatively large resources, and (3) warrant special management attention. Additional criteria and relative dollar threshold for the determination of agency programs to be cons red major systems under the purview of this Circu , may be established at the discretion of the agency hea

i. *System acquisition process* means the .ence of acquisition activities starting from t.. agency's reconciliation of its mission needs, with its capabilities, priorities and resources, and extending through the introduction of a system into operational use or the otherwise successful achievement of program objectives.

j. *Life cycle cost* means the sum total of the direct, indirect, recurring, nonrecurring, and other related costs incurred, or estimated to be incurred, in the design, development, production, operation, maintenance and support of a major system over its anticipated useful life span.

6. *General policy*. The policies of this Circular are designed to assure the effectiveness and efficiency of the process of acquiring major systems. They are based on the general policy that Federal agencies, when acquiring major systems, will:

a. Express needs and program objectives in mission terms and not equipment terms to encourage innovation and competition in creating, exploring, and developing alternative system design concepts.

b. Place emphasis on the initial activities of the system acquisition process to allow competitive exploration of alternative system design concepts in response to mission needs.

c. Communicate with Congress early in the system acquisition process by relating major system acquisition programs to agency mission needs. This communication should follow the requirements of Office of Management and Budget (OMB) Circular No. A-10 concerning information related to budget estimates and related materials.

d. Establish clear lines of authority, responsibility, and accountability for management of major system acquisition programs. Utilize appropriate managerial levels in decisionmaking, and obtain agency head approval at key decision points in the evolution of each acquisition program.

e. Designate a focal point responsible for integrating and unifying the system acquisition management process and monitoring policy implementation.

f. Rely on private industry in accordance with the policy established by OMB Circular No. A-76.

7. Major system acquisition management objectives. Each agency acquiring major systems should:

a. Ensure that each major system: Fulfills a mission need. Operates effectively in its intended environment. Demonstrates a level of performance and reliability that justifies the allocation of the Nation's limited resources for its acquisition and ownership.

b. Depend on, whenever economically beneficial, competition between similar or differing system design concepts throughout the entire acquisition process.

c. Ensure appropriate trade-off among investment costs, ownership costs, schedules, and performance characteristics.

d. Provide strong checks and balances by ensuring adequate system test and evaluation. Conduct such tests and evaluation independent, where practicable, of developer and user.

e. Accomplish system acquisition planning, built on analysis of agency missions, which implies appropriate resource allocation resulting from clear articulation of agency mission needs.

f. Tailor an acquisition strategy for each program, as soon as the agency decides to solicit alternative system design concepts, that could lead to the acquisition of a new major system and refine the strategy as the program proceeds through the acquisition process. Encompass test and evaluation criteria and business management considerations in the strategy. The strategy could typically include: ° Use of the contracting process as an important tool in the acquisition program ° Scheduling of essential elements of the acquisition process ° Demonstration, test, and evaluation criteria ° Content of solicitations for proposals ° Decisions on whom to solicit ° Methods for obtaining and sustaining competition ° Guidelines for the evaluation and acceptance or rejection of proposals ° Goals for design-to-cost ° Methods for projecting life cycle costs ° Use of data rights ° Use of warranties ° Methods for analyzing and evaluating contractor and Government risks ° Need for developing contractor incentives ° Selection of the type of contract best suited for each stage in the acquisition process ° Administration of contracts.

g. Maintain a capability to: ° Predict, review, assess, negotiate and monitor costs for system development, engineering, design, demonstration, test, production, operation and support (i.e., life cycle costs) ° Assess acquisition cost, schedule and performance experience against predictions, and provide such assessments for consideration by the agency head at key decision points ° Make new assessments where significant costs, schedule or performance variances occur ° Estimate life cycle costs during system design concept evaluation and selection, full-scale development, facility conversion, and production, to ensure appropriate trade-offs among investment costs, ownership costs, schedules, and performance ° Use independent cost estimates, where feasible, for comparison purposes.

8. Management structure.

a. The head of each agency that acquires major systems will designate an acquisition executive to integrate and unify the management process for the agency's major system acquisitions and to monitor implementation of the policies and practices set forth in this Circular.

b. Each agency that acquires--or is responsible for activities leading to the acquisition of--major systems will

establish clear lines of authority, responsibility, and accountability for management of its major system acquisition programs.

c. Each agency should preclude management layering and placing reporting procedures and paperwork requirements on program managers and contractors.

d. A program manager will be designated for each of the agency's major system acquisition programs. This designation should be made when a decision is made to fulfill a mission need by pursuing alternative system design concepts. It is essential that the program manager have an understanding of user needs and constraints, familiarity with development principles, and requisite management skills and experience. Ideally, management skills and experience would include: ° Research and development ° Operations ° Engineering ° Construction ° Testing ° Contracting ° Prototyping and fabrication of complex systems ° Production ° Business ° Budgeting ° Finance. With satisfactory performance, the tenure of the program manager should be long enough to provide continuity and personal accountability.

e. Upon designation, the program manager should be given budget guidance and a written charter of his authority, responsibility, and accountability for accomplishing approved program objectives.

f. Agency technical management and Government laboratories should be considered for participation in agency mission analysis, evaluation of alternative system design concepts, and support of all development, test, and evaluation efforts.

g. Agencies are encouraged to work with each other to foster technology transfer, prevent unwarranted duplication of technological efforts, reduce system costs, promote standardization, and help create and maintain a competitive environment for an acquisition.

9. Key decisions. Technical and program decisions normally will be made at the level of the agency component or operating activity. However, the following four key decision points should be retained and made by the agency head:

a. Identification and definition of a specific mission need to be fulfilled, the relative priority assigned within the agency, and the general magnitude of resources that may be invested.

b. Selection of competitive system design concepts to be advanced to a test/demonstration phase or authorization to proceed with the development of a noncompetitive (single concept) system.

c. Commitment of a system to full-scale development and limited production.

d. Commitment of a system to full production.

10. Determination of mission needs.

a. Determination of mission need should be based on an analysis of an agency's mission reconciled with overall capabilities, priorities and resources. When analysis of an agency's mission shows that a need for a new major system exists, such a need should not be defined in equipment terms, but should be defined in terms of the mission, purpose, capability, agency components involved, schedule and cost objectives, and operating constraints. A mission need may result from a deficiency in existing agency capabilities or the decision to establish new capabilities in response to a technologically feasible opportunity. Mission needs are independent of any particular system or technological solution.

b. Where an agency has more than one component involved, the agency will assign the roles and responsibilities of each component at the time of the first key decision. The agency may permit two or more agency components to sponsor competitive system design concepts in order to foster innovation and competition.

c. Agencies should, as required to satisfy mission responsibilities, contribute to the technology base, effectively utilizing both the private sector and Government laboratories and in-house technical centers, by conducting, supporting, or sponsoring: ° Research ° System design concept studies ° Proof of concept work ° Exploratory subsystem development ° Tests and evaluations. Applied technology efforts oriented to system developments should be performed in response to approved mission needs.

11. Alternative systems.

a. Alternative system design concepts will be explored within the context of the agency's mission need and program objectives--with emphasis on generating innovation and conceptual competition from industry. Benefits to be derived should be optimized by competitive exploration of alternative system design concepts, and trade-offs of capability, schedule, and cost. Care should be exercised during the initial steps of the acquisition process not to conform mission needs or program objectives to any known systems or products that might foreclose consideration of alternatives.

b. Alternative system design concepts will be solicited from a broad base of qualified firms. In order to achieve the most preferred system solution, emphasis will be placed on innovation and competition. To this end, participation of smaller and newer businesses should be encouraged. Concepts will be primarily solicited from private industry; and when beneficial to the Government, foreign technology, and equipment may be considered.

c. Federal laboratories, federally funded research and development centers, educational institutions, and other not-for-profit organizations may also be considered as sources for competitive system design concepts. Ideas, concepts, or technology, developed by Government laboratories or at Government expense, may be made available to private industry through the procurement process or through other established procedures. Industry proposals may be made on the basis of these ideas, concepts, and technology or on the basis of feasible alternatives which the proposer considers superior.

d. Research and development efforts should emphasize early competitive exploration of alternatives, as relatively inexpensive insurance against premature or preordained choice of a system that may prove to be either more costly or less effective.

e. Requests for alternative system design concept proposals will explain the mission need, schedule, cost, capability objectives, and operating constraints. Each offeror will be free to propose his own technical approach, main design features, subsystems, and alternatives to schedule, cost, and capability goals. In the conceptual and

less than full-scale development stages, contractors should not be restricted by detailed Government specifications and standards.

f. Selections from competing system design concept proposals will be based on a review by a team of experts, preferably from inside and outside the responsible component development organization. Such a review will consider: (1) Proposed system functional and performance capabilities to meet mission needs and program objectives, including resources required and benefits to be derived by trade-offs, where feasible, among technical performance, acquisition costs, ownership costs, time to develop and procure; and (2) The relevant accomplishment record of competitors.

g. During the uncertain period of identifying and exploring alternative system design concepts, contracts covering relatively short time periods at planned dollar levels will be used. Timely technical reviews of alternative system design concepts will be made to effect the orderly elimination of those least attractive.

h. Contractors should be provided with operational test conditions, mission performance criteria, and life cycle cost factors that will be used by the agency in the evaluation and selection of the system(s) for full-scale development and production.

i. The participating contractors should be provided with relevant operational and support experience through the program manager, as necessary, in developing performance and other requirements for each alternative system design concept as tests and trade-offs are made.

j. Development of subsystems that are intended to be included in a major system acquisition program will be restricted to less than fully designed hardware (full-scale development) until the subsystem is identified as a part of a system candidate for full-scale development. Exceptions may be authorized by the agency head if the subsystems are long lead time items that fulfill a recognized generic need or if they have a high potential for common use among several existing or future systems.

12. Demonstrations.

a. Advancement to a competitive test/demonstration phase may be approved when the agency's mission need and program objectives are reaffirmed and when alternative system design concepts are selected.

b. Major system acquisition programs will be structured and resources planned to demonstrate and evaluate competing alternative system design concepts that have been selected. Exceptions may be authorized by the agency head if demonstration is not feasible.

c. Development of a single system design concept that has not been competitively selected should be considered only if justified by factors such as urgency of need, or by the physical and financial impracticality of demonstrating alternatives. Proceeding with the development of a noncompetitive (single concept) system may be authorized by the agency head. Strong agency program management and technical direction should be used for systems that have been neither competitively selected nor demonstrated.

13. Full-scale development and production.

a. Full-scale development, including limited production, may be approved when the agency's mission need and program objectives are reaffirmed and competitive demonstration results verify that the chosen system design concept(s) is sound.

b. Full production may be approved when the agency's mission need and program objectives are reaffirmed and when system performance has been satisfactorily tested, independent of the agency development and user organizations, and evaluated in an environment that assures demonstration in expected operational conditions. Exceptions to independent testing may be authorized by the agency head under such circumstances as physical or financial impracticability or extreme urgency.

c. Selection of a system(s) and contractor(s) for full-scale development and production is to be made on the basis of (1) system performance measured against current mission need and program objectives, (2) an evaluation of estimated acquisition and ownership costs, and (3) such factors as

contractor(s) demonstrated management, financial, and technical capabilities to meet program objectives.

d. The program manager will monitor system tests and contractor progress in fulfilling system performance, cost, and schedule commitments. Significant actual or forecast variances will be brought to the attention of the appropriate management authority for corrective action.

14. Budgeting and financing. Beginning with FY 1979 all agencies will, as part of the budget process, present budgets in terms of agency missions in consonance with Section 201(i) of the Budget and Accounting Act, 1921, as added by Section 601 of the Congressional Budget Act of 1974, and in accordance with OMB Circular A-11. In so doing, the agencies are desired to separately identify research and development funding for: (1) The general technology base in support of the agency's overall missions, (2) The specific development efforts in support of alternative system design concepts to accomplish each mission need, and (3) Full-scale developments. Each agency should ensure that research and development is not undesirably duplicated across its missions.

15. Information to Congress.

a. Procedures for this purpose will be developed in conjunction with the Office of Management and Budget and the various committees of Congress having oversight responsibility for agency activities. Beginning with FY 1979 budget each agency will inform Congress in the normal budget process about agency missions, capabilities, deficiencies, and needs and objectives related to acquisition programs, in consonance with Section 601(i) of the Congressional Budget Act of 1974.

b. Disclosure of the basis for an agency decision to proceed with a single system design concept without competitive selection and demonstration will be made to the congressional authorization and appropriation committees.

16. Implementation. All agencies will work closely with the Office of Management and Budget in resolving all implementation problems.

17. Submissions to Office of Management and Budget. Agencies will submit the following to OMB:

a. Policy directives, regulations, and guidelines as they are issued.

b. Within six months after the date of this Circular, a time-phased action plan for meeting the requirements of this Circular.

c. Periodically, the agency approved exceptions permitted under the provisions of this Circular.

This information will be used by the OMB, in identifying major system acquisition trends and in monitoring implementations of this policy.

18. Inquiries. All questions or inquiries should be submitted to the OMB, Administrator for Federal Procurement Policy. Telephone number, area code, 202-395-4677.

Hugh E. Witt
HUGH E. WITT
ADMINISTRATOR FOR
FEDERAL PROCUREMENT POLICY

Approved:
James T. Lynn
JAMES T. LYNN
DIRECTOR

APPENDIX C

REFERENCES

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AFSC Design Handbook Human Factors Engineering, Series 1-0, Wright-Patterson Air Force Base, Ohio: Department of the Air Force, Aeronautical Systems Division, 1977

Aircrew Station Signals, Military Standard MIL-STD-411D, 1970

Alexander, M., Garrett, J.W., Flannery, M.P. "Anthropometric Dimensions of the Air Force Pressure-suited Personnel for Workspace and Design Criteria" Wright-Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratory, Air Force Systems Command, 1969. AD 697022

Anderson, A.F., Renshaw, K.S., Whitmore, D.C. "Computer Aided Function-Allocation Evaluation System, Volume 2" Seattle, Washington: Boeing Aerospace Company, 1974

Appendix I, Glossary of Terms, OPNAV Instruction 1000.16D, 1977

Aume, N.M., Topmiller, D.A. "Human Engineering Computer Aided Design (HECAD)" from the Proceedings of the 16th Annual Meeting of the Human Factors Society, 1972

Ayoub, M.A., Smillie, R.J., Edsall, J.C., and Mullen, W.G. "A Computerized Approach for the Assessment and Evaluation of Job Performance Aids" Raleigh, North Carolina: North Carolina State University, 1976

Baise, E.J., Miller, J.M. (Eds.) Proceedings of the Human Factors Society 22nd Annual Meeting. Detroit, Michigan: Engineering Human Performance and Safety Research Laboratory, the University of Michigan, 1978

Baker, C.C., and Malone, T.B. "Human Factors Engineering Evaluation of Catapult Systems" Alexandria, Virginia: Essex Corporation, 1978

Beek, C., Haynan, K., and Markisohn, G. "Human Reliability Research" Silver Spring, Maryland: Operations Research, Inc., 1967. AD 664 495

Bittner, A.C., Computerized Accommodated Percentage Evaluation; Review and Prospectus, PNTC, 1976

Bittner, A.C., Jr. and Moroney, W.F. "The Accommodated Proportion of a Potential User Population: Compilation and Comparisons of Methods for Estimation" Point Magu, California: Pacific Missile Test Center, 1975

Boneau, C.A., "Mission Sponsor Plan" Essex Corporation, 1979

Booher, H.R. "Status of Job Performance Aids Technology: Analysis and Conclusions" from Symposium Proceedings: Invitational Conference on Status of Job Performance Aids Technology, 1977. ADA040540

Braby, R., Henry, J.M., Morris, C.L., Jr. "A Technique for Choosing Cost-Effective Instructional Media" Orlando, Florida: Training Analysis and Evaluation Group (TAEG), 1974

Campbell, J.O., and Hughes, J. "Optimizing Media Selection" Proceedings of the 11th NTEC - Industry Conference, 1978

Carrier Landing Performance Conference (Proceedings), Johnson, J.H. (Chairman), Norfolk, Virginia: Naval Air Station, 1976

Casey, G.A., Sturm, W.P. "Human Factors Engineering in Navy Systems Acquisition" Monterey, California: Naval Postgraduate School, 1974

Chenzoff, A.P., and Folley, J.O., Jr. "Guidelines for Training Situation Analysis (TSA)," Technical Report No. 1218-4, Orlando, Florida: Naval Training Device Center, 1965

Coburn, R. "Human Engineering Guide to Ship System Development Responsibilities, Procedures, and Methods for Carrying Out Human Engineering Programs" San Diego, California: Naval Electronics Laboratory Center, 1973

Coburn, R., and Lowe, T.D. "Human Factors Engineering Integration for Ship Systems: FY-76 Report on Methodology for Command Control and Communications" San Diego, California: Naval Electronics Laboratory Center, 1976

Colwell, M.C., Risk, D.M., and Reed, L.E. "TREES User's Guide: A Computer Software System for Handling Information in Branch Form" Dayton, Ohio: System Development Corporation, 1971, AD732209

Colwell, M.C. "TREES: A Computer Software System for Processing Data Organized in Branch Form (An Application to Job Performance Aids) Volume I: Design and Development" Dayton, Ohio: System Development Corporation, 1971, AD732204

Colwell, M.C., and Risk, D.M. "TREES: A Computer Software System for Processing Data Organized in Branch Form (An Application to Job Performance Aids) Volume II: Program Descriptions" Dayton, Ohio: System Development Corporation, 1971, AD735603

Control Panel, Aircraft, General Requirements For, Military Specification, MIL-C-81774A, 1973

Curry, R.E., Hoffman, W.C., and Young, L.R. "Pilot Modeling for Manned Simulation, Volume I" Burlington, Massachusetts: Aerospace Systems, Inc., 1976, ADA047071

Deardorff, D.C., Hageman, K.C., Stockton, C.E. "Human Factors Engineering (HFE) Program Planning" Fort Worth, Texas: Hageman Consulting Services, 1974

Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety. Military Standard MIL-STD-721B, 1966

Department of the Navy Integrated Logistic Support (ILS) Systems, OPNAV Instruction 4100.3A, 1972

DeMaree, R.C. "Development of Training Equipment Planning Information" USAF, ASD, T.R. 61-533, 1961

Duket, S.D., and Wortman, D.B. "Documentation for the SAINT Simulation Program" Lafayette, Indiana: Pritsker and Associates, Inc., 1976

Edwards, R.E., Renshaw, K.S., Healy, M.J., and Atkins, R.A. "Computer Aided Function Allocation Evaluation System (CAFES)" Seattle, Washington: Boeing Aerospace Company, 1976, ADA033856

Ellis, R.H. "Task Analysis Reduction Technique (TART) for the Quantification of Human Performance" San Diego, California: Naval Personnel and Training Research Laboratory, 1970

Evans, S.M. "User's Guide for the Programs of COMBIMAN (Computerized Biomechanical Man-Model" Dayton, Ohio: University of Dayton Research Institute, 1976, ADA038323

Evans, S.M., Himes, M.J., and Kikta, P.E. "Biomechanics and Anthropometry for Cockpit and Equipment Design" Dayton, Ohio: University of Dayton Research Institute, 1976, ADA037020

Human Factors Engineering Design for Army Material. Military Standardization Handbook, MIL-HDBK-759, 1975

Folley, J.D., Jr. (Ed.) Human Factors Methods for System Design, The American Institute for Research, 1960

Freeman, R.G. III "Trends in Acquisition" Fort Belvoir, Virginia: Defense Systems, Management College, 1978

Freund, L.E., and Sadosky, T.L. "Linear Programming Applied to Optimization of Instrument Panel and Workspace Layout" Human Factors, Volume 9, No. 4, Ann Arbor, Michigan: University of Michigan, 1967

Funaro, J.F., and Mulligan, B.E. "Naval Aviation Instructional Systems Development" from Proceedings of 11th NTEC-Industry Conference, 1978

Greer, C.W. "Analyst's Guide for the Analysis Sections of MIL-H-46855" Seattle, Washington: Boeing Aerospace Company, 1976

Greer, C.W. "Navy Manager's Guide for the Test and Evaluation Sections of MIL-H-46855" Seattle, Washington: Boeing Aerospace Company, 1977

Greer, C.W. "User's Guide for the Test and Evaluation Sections of MIL-H-46855" Seattle, Washington: Boeing Aerospace Company, 1977

Goclowski, J.C., King, G.F., Ronco, P.G., and Askreen, W.B. "Integration and Application of Human Resource Technologies in Weapon System Design: Coordination of Five Human Resource Technologies" Wilmington, Massachusetts: Dynamics Research Corporation, 1978, ADA053680

Hann, R.L., and Kuperman, G.G. "SAINT Model of a Choice Reaction Time Paradigm" Wright-Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratory, 1976, ADA027931

Heglin, H.J. "Naval Ship Systems Command Display Illumination Design Guide, Section II: Human Factors" San Diego, California: Naval Electronics Laboratory Center, 1973

Helm, W.R. "The Function Description Inventory as a Human Factors Tool in Evaluating System Effectiveness in Operational Environments" Patuxent River, Maryland: Naval Air Center, 1975

Hertzberg, H.T.E. "Engineering Anthropology" in Van Cott, H.P. and Kinkade, R.G. (Eds.) Human Engineering Guide to Equipment Design, 1977

Hitchchock, L., Jr. "F-18 Interior Lighting Analysis: Red vs. White" Warminster, Pennsylvania: Naval Air Development Center, 1976, ADA031695

Holshouser, E.L. "Guide to Human Factor Engineering General Purpose Test Planning" Point Magu, California: Pacific Missile Test Center, 1977

Holshouser, E.L. "Translation of DSARC Milestones into Human Factors Engineering Requirements" Point Magu, California: Pacific Missile Test Center, 1975

Holshouser, E.L. "Development of DSARC-Based Human Factors Engineering Test and Evaluation Requirements for the F-18 Aircraft Weapon System" Point Magu, California: Pacific Missile Test Center, 1978

Holshouser, E.L. "Translation of DSARC Milestones into Human Factors Engineering Requirements" Point Magu, California: Pacific Missile Test Center, 1975

"Human Engineering Design Criteria for Military Systems, Equipment, and Facilities" Military Standard MIL-STD-1472B, 1974

"Human Engineering Requirements Manual for Evolving Systems (HERMES), Volumes I and II" Warminster, Pennsylvania: Naval Air Development Center, 1974. ADA012154, ADA012155

"Human Engineering Requirements for Military Systems, Equipment, and Facilities" Military Specification MIL-H-46855A

"Human Factors Engineering Systems Analysis Data" Military Specification MIL-H-81444 (AS), 1966

"Integrated Logistic Support (ILS) Planning Policy" NAVMAT Instruction 4000.20B, 1975

Joyce, R.P. "Performance Aids and Technical Training: Complementary Information Sources" from New Concepts in Maintenance Trainers and Performance Aids, Orlando, Florida: Naval Training Equipment Center, 1975

Kearsley, G.P., and O'Neal, A.I. "The Role of Simulation in Large Scale Instructional System Development (ISD)" from Proceedings of the 11th NTEC-Industry Conference, 1978

Kennedy, R.S., and Bittner, A.C., Jr. "Progress in the Analysis of a Performance Evaluation Test for Environmental Research (PETER)" from the Proceedings of the Human Factors Society - 22nd Annual Meeting, 1978

Kidd, S.S. and Van Cott, H.P. "System and Human Engineering Analysis," in Van Cott and Kinkade (Eds.) Human Engineering Guide to Equipment Design, 1972

Knowles, W.B., Sanders, M.S., and Muckler, F.A. (Eds.) Proceedings of the 16th Annual Meeting of the Human Factors Society - Technology for Man, 1972

Lahey, G.F. "Automating the Operational Sequence Diagram (OSD)" San Diego, California: Naval Personnel and Training Research Laboratory, 1970, AD718842

Larson, O.A., and Willis, J.E. "Human Factors Methods Development and Test: II. Evaluation of the Automated Operational Sequence Diagram (OSD)" San Diego, California: Naval Personnel and Training Research Laboratory, 1970, AD707719

Lintz, L.M., Loy, S.L., Brock, G.R., and Potempa, K.W. "Predicting Maintenance Task Difficulty and Pesonnel Skill Requirements Based on Design Parameters of Avionics Subsystems" St. Louis, Missouri: McDonnell Douglas Astronautics Company, 1973, AD768415

Logan, R.S. "A Survey and Analysis of Military Computer-Based Systems" A Two Part Study. Volume I. A Survey and Annotated Bibliography of Aids for Instructinal Systems Development" St. Louis, Missouri: McDonnell Douglas Aeronautics Company - East, 1977. ADA036912

Maintainability Prediction. Military Standardization Handbook-472, 1966

Maintainability Verification/Demonstration/Evaluation. Military Standard 471A, 1973

Major System Acquisition Process, DOD Directive 5000.2, 1977

Major System Acquisitions, DOD Directive 5000.1, 1977

Malone, T.B., Andrews, P.J., Lewis, W., and McGuinness, J. "Human Factors Engineering Technology Integration Into the Naval Ship Acquisition Process" Proceedings of the Human Factors Society 21st Annual Meeting, 1977

Malone, T.B., and Eike, D.R. "Human Factors Engineering Technology Applied to the Beartrap Recovery Assist, Secure, and Traverse (RAST) System Landing Signal Officer (LSO) Console Design" Alexandria, Virginia: Essex Corporation, 1978

Malone, T.B., Kirkpatrick, M., McGuinness, J., and Kohl, J.S. "Human Factors Engineering Technology for Ship Acquisition" Volume II, Appendices A-F, Alexandria, Virginia: Essex Corporation, 1976

Malone, T.B., Kirkpatrick, M., McGuinness, J., and Kohl, J.S. "Human Factors Engineering Technology for Ship Acquisition" Volume I and II, Alexandria, Virginia: Essex Corporation, 1976

Malone, T.B., and Shenk, S.W. "U.S. Army Test and Evaluation Command Test Operations Procedure, Cold Regions Human Factors Engineering" Part I. Test Procedures. Alexandria, Virginia: Essex Corporation, 1978

Malone, T.B., and Shenk, S.W. "Human Factors Test and Evaluation Manual" Volumes I, II, III. Alexandria, Virginia: Essex Corporation, 1976

Malone, T.B., and Shenk, S.W. "U.S. Army Test and Evaluation Command Test Operations Procedure Cold Regions Human Factors Engineering" Part I: Test Procedures and Part II: Human Factors Engineering Data Guide for Evaluation (HEDGE). Alexandria, Virginia: Essex Corporation, 1978

Meister, D. "Comparative Analysis of Human Reliability Models" Westlake Village, California: Bunker Ramo Corporation, 1971

Meister, D. "A Systematic Approach to Human Factors Measurement" San Diego, California: Navy Personnel Research and Development Center, 1978

Meister, D. "Comparative Analysis of Human Reliability Models" West Lake, California: Bunker-Ramo Corporation, 1971. AD734432

Meister, D., and Mills, R.G. "Development of a Human Performance Reliability Data System: Phase I" Westlake Village, California: Bunker-Ramo Corporation, 1971. AD738322

Meister, D., and Rabideau, G. Human Factors Evaluation in System Development, New York: John Wiley & Sons, Inc., 1965

Meister, D., and Sullivan, D.J. "Guide to Human Engineering Design for Visual Displays" Canoga Park, California: Bunker-Ramo Corporation, 1969

Merriman, S.C. "Human Factors Programs in Navy Systems Acquisition Study Project Report" Fort Belvoir, Virginia: Defense Systems Management College, 1976

Miehle, W., and Siegel, A.I. "Extension of the Display Evaluative Index (DEI) Technique for Multioperator Situations" Wayne, Pennsylvania: Applied Psychological Services Science Center, 1965. AD456019

Military Specification Human Engineering Requirements for Military Systems, Equipment, and Facilities, 1972, MIL-H-46855a

Miller, K.H. "Timeline Analysis Program (TLA-1)" Seattle, Washington: Boeing Commercial Airplane Company, 1976

Miller, R.B. "A Classification of Learning Tasks in Conventional Language." USAF, MRL, TOR, 63-74, 1963

Mockups, Aircraft, General Specification for, Military Specification MIL-M-8650C, 1976

Moroney, W.F., and Smith, M.J. "Empirical Reducation in Potential User Population as the Result of Imposed Multivariate Anthropometric Limits" Pensacola, Florida: Naval Aerospace Medical Research Laboratory, 1972

Mullen, P.A., and Joyce, R.P. "Demonstration of Fully Proceduralized Job Performance Aids and Matching Training" Valencia, Pennsylvania: Applied Sciences Associates, Inc., 1974

O'Connor, M.F., and Buede, D.M. "The Application of Decision Analytic Techniques to the Test and Evaluation Phase of the Acquisition of a Major Air System" McLean, Virginia: Decisions and Designs, Inc., 1977. ADA040691

"Operational Performance Recording and Evaluation Data System" San Diego, California: Naval Electronics Laboratory Center, undated

Operational Stations Book (OSB), Military Specification MIL-D-24312A (Ships), 1969

Parks, D.L., and Springer, W.E. "Human Factors Engineering Analytic Process Definition and Criterion Development for Computer-Aided Function Allocation Evaluation Systems (CAFES)" Seattle, Washington: Boeing Aerospace Company, 1976. ADA040478

Plato, A.I., and Gambrel, W.D., Jr. "The U.S. Navy's Design Work Study Approach to the Development of Shipboard Control Systems" Washington, D.C.: NAVSEC, 1975. ADA022314

Post, T. "Selection of Formats and Media for Presenting Maintenance Information" Symposium Proceedings: Invitational Conference on Status of Job Performance Aids Technology, 1977. ADA040540

Post, T., Price, H., and Diffley, G. "A Guide for Selecting Formats and Media for Presenting Maintenance Information" Falls Church, Virginia: Biotechnology, Inc., 1976. ADA033921

Potempa, K.W. "A Catalog of Human Factors Techniques for Testing New Systems" Wright Patterson Air Force Base, Ohio: Air Force Human Resources Laboratory, 1969. AD854482

Rabideau, G.F., and Luk, R.H. "A Monte Carlo Algorith for Workplace Optimization and Layout Planning (WOLAP)" Waterloo, Ontario, Canada: University of Waterloo, 1974

Ramsey, H.R., Atwood, M.E., and Kirshbaum, P.J. "A Critically Annotated Bibliography of the Literature on Human Factors in Computer Systems" Englewood, Colorado: Science Applications, Inc., 1978

Roeder, J.T., and Ranc, M.P, Jr. "Comparative Studies on FOMM, Learning the FOMM Language, and Possibilities for Automation of Functionally Oriented Maintenance Manuals (FOMM's)" from New Concepts in Maintenance Trainers and Performance Aids, Orlando, Florida: Naval Training Equipment Center, 1975

Section IV - Development Proposal (DP) Contents Program Title, OPNAV Instruction 5000.42A, 1976

Sherrill, J.L. "Task Analysis of Job Contents to Support Criteria Design" Fort B. Harrison, Indiana: U.S. Army Institute of Administration. Presented at Second Annual Job Information Presentation Conference, Washington, D.C., 1976

Ship Acquisition Reef Points. Washington, D.C.: Naval Sea Systems Command, 1976

Shriver, E.L. "Fully Procedurablized Job Performance Aids: Guideance for Performing Behavioral Analyses of Tasks" Fall Church, Virginia: USR/Matrix Research Company, 1975. ADA015059

Siegel, A.I., and Federman, P.J. "Prediction of Human Reliability. Development and Test of a Human Reliability Predictive Technique for Application in Electronic Maintainability Prediction" Wayne, Pennsylvania: Applied Psychological Services, 1971. AD738572

Siegel, A.I., Fischl, M.A., and MacPherson, O. "The Analytic Profile System (APS) for Evaluating Visual Displays" Human Factors, 1975, 17 (3), 278-288

Siegel, A.I., Leahy, W.R., and Wiesen, J.P. "Applications of Human Performance Reliability Evaluation Concepts and Demonstration Guidelines" Wayne, Pennsylvania: Applies Psychological Services, Inc., 1977. ADA037632

Siegel, A.I., Wolf, J.J., and Cosentino, J. "Digital Simulation of the Performance of Intermediate Size Crews: Application and Validation of a Model for Crew Simulation" Wayne, Pennsylvania: Applied Psychological Services, Inc., 1971

Siegel, A.I., Wolf, J.J., and Lautman, M.R. "A Model for Predicting Integrated Man-Machine System Reliability: Model Logic and Description" Wayne, Pennsylvania: Applied Psychological Services, Inc., 1974. ADA009814

Siegel, A.I., Wolf, J.J., and Leahy, W.R. "A Digital Simulation Model of Message Handling in the Tactical Operations System: I. The Model, Its Sensitivity, and User's Manual" Wayne, Pennsylvania: Applied Psychological Services, Inc., 1977. ADA047104

Siegel, A.I., Wolf, J.J., and Williams, A.R. "A Model for Predicting Integrated Man-Machine Reliability II. Model Validation" Wayne, Pennsylvania: Applied Psychological Services, Inc., 1976. ADA023886

Springer, W.E., and Ryan, P.W. "Cockpit Geometry Evaluation - Phase I. Human Data" Seattle, Washington: The Boeing Company, 1969. AD703268

Steeb, R., Weltman, G., and Freedy, A. "Man/Machine Interaction in Adaptive Computer-Aided Control: Human Factors Guidelines" Woodland Hills, California: Perceptronics, 1976. ADA021721

Strieb, M.I., Glenn, F.A., and Wherry, R.J. "The Human Operator Simulator, Volume IX - HOS Study Guide" Willow Grove, Pennsylvania: Analytics, 1978

System Acquisition in the Department of the Navy, SECNAV Instruction 5000.1A, 1972

Tannenbaum, J.J. "Apportioning Information Among Personnel Subsystem Documents: the MAP Process" Unpublished paper presented at First Annual Learning Technology Congress and Exposition on Applied Learning Technology for Human Resources Development, 1976

Test and Evaluation. DOD Directive 5000.3, 1973

Test and Evaluation. NAVMAT Instruction 3960.6A, 1976

Test and Evaluation. OPNAV Instruction 3960.10, 1975

Tetmeyer, C.D., Nichols, S.R., Hart, W.L., and Maher, F.A. "Simulators Maintenance Manning for New Weapon Systems: Maintenance Manpower Matrix Program," Advanced Systems Division, WPAFB, Ohio, 1976

Thomson, R.M. "Design of Multi-Man Machine Work Areas" Human Engineering Guide to Equipment Design, Van Cott, H.P., and Kincade, R.G. (Eds.), Washington, D.C.: American Institute for Research, 1972

Uhlaner, J.E., Zeidner, J., Dusek, E.R., and Sasmor, R.M. "Research Themes and Technological Base Program in Behavioral and Social Sciences for the U.S. Army" Alexandria, Virginia: U.S. Army Research Institute for the Behavioral and Social Sciences, Department of the Army, 1978

Ulvila, J.W., Brown, R.V., and Randall, L.S. "Step-through Simulation: A Method for Implementing Decision Analysis" McLean, Virginia: Decisions and Designs, Inc., 1976. ADA036969

Van Cott, H.P., and Kincade, R.G. Human Engineering Guide to Equipment Design, Washington, D.C.: American Institute for Research, 1972

Whitman, D.C., and Parks, D.L. "Computer Aided Function-Allocation Evaluation System" Volume I. Seattle, Washington: Boeing Aerospace Company, 1974

Wierwilles, W.W., and Williges, R.C. "Survey and Analysis of Operator Workload Assessment Techniques" Blacksburg, Virginia: Systemetrics, Inc., 1978

Woodson, W., and Selby, P. "Databook for Human Factors Engineers" Volume I: Human Engineering Data-Man Factors, Inc., 1969

Wortman, D.B., and Duket, S.D. "Simulation Using SAINT; A User-Oriented Instruction Manual" Lafayette, Indiana: Pritsker and Associates, Inc., 1976

Wortman, D.B., and Duket, S.D. "The SAINT User's Manual" Lafayette, Indiana: Pritsker and Associates, Inc., 1976